THE NEW IRRIGATION ERA

JOURNAL OF THE IRRIGATION BRANCH, MADRAS P.W.D.

VOLUME III

NUMBER 6

DAM & HEAD-WORKS OF A TYPICAL IRRIGATION SYSTEM—A WORKING MODEL

FEBRUARY 1954
TO
APRIL 1954

FOR DEPARTMENTAL CIRCULATION ONLY.

OUR FRONT COVER.

The need for educating public opinion in respect of the various activities of the Government especially in relation to the Five Year Plan has been well recognised. Exhibitions suitably planned and organised in different centres, during times when a large concourse of people foregather for some public function or festival or on a holiday, are known to constitute one of the best methods of attracting the interest of the common man to a just realisation of what the Government is planning to do, and what it is striving for towards reaching the goal of general prosperity in a welfare State.

The Irrigation Branch of the Public Works Department of the Madras Government, as usual, took part in the All India Khadhi, Swadeshi and Industrial Exhibition held in Madras from 22nd December 1953 to 8th February 1954 with the sole purpose of putting before the public the details of the Irrigation Projects, existing under construction and under active consideration within the State. The Five Year Plan and the Projects taken up for execution under that plan were especially stressed in models, in pictures and in charts in order to make the people "Plan Minded".

The stall put up by the Department was one of the main attractions in the exhibition and, millions of people both from the City as well as from the mofussil visited it during this period. They evinced keen interest in and were appreciative of the educative value of the many and varied exhibits put up therein.

The Front Cover of this issue carries a Photograph of the portion of a model of a "Typical Irrigation System" which was one of the "starred" exhibits. The model was a comprehensive one incorporating with meticulousness in detail the incidence of rainfall, flooding of rivers, damming across a valley, take off and surplus arrangements at head works and distribution systems

Elsewhere in this issue is featured a descriptive article on the exhibition together with an art supplement containing photographs of the important exhibits.

CONTRIBUTIONS INVITED.

Attention of the readers is invited to Circular No. 392/51-1952 dated 26-11-1952 inviting articles and papers for publication in the New Irrigation Era. The Chief Engineer regrets that in spite of appeals and invitations, the contributions to the journal by the Officers of the Department and others have been much below expectations. The Officers of the Department, Principals of the Engineering Colleges, Officers of the Sister Engineering Departments in the State and others interested in the Science and Development of Irrigation are requested to contribute articles and papers in very good numbers.

For 'Instructions to Contributors' reference is invited to pages 245, 246, 247, 248, of Volume II. Copies may be had on writing to the Editor, Post Box No. 416, Chepauk, Triplicane Madras-5.

THE NEW IRRIGATION ERA

(Journal of the Irrigation Branch, Madras P. W. D.)

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THE NEW IRRIGATION ERA

Published by the Irrigation Branch of the Madras Public Works Department, Madras (5), South India.

(For Departmental Circulation only)

" I believe in Hands that work,
Brains that think and
Hearts that love."
—Elbert Hubbard.

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HOW WOULD YOU DO IT?

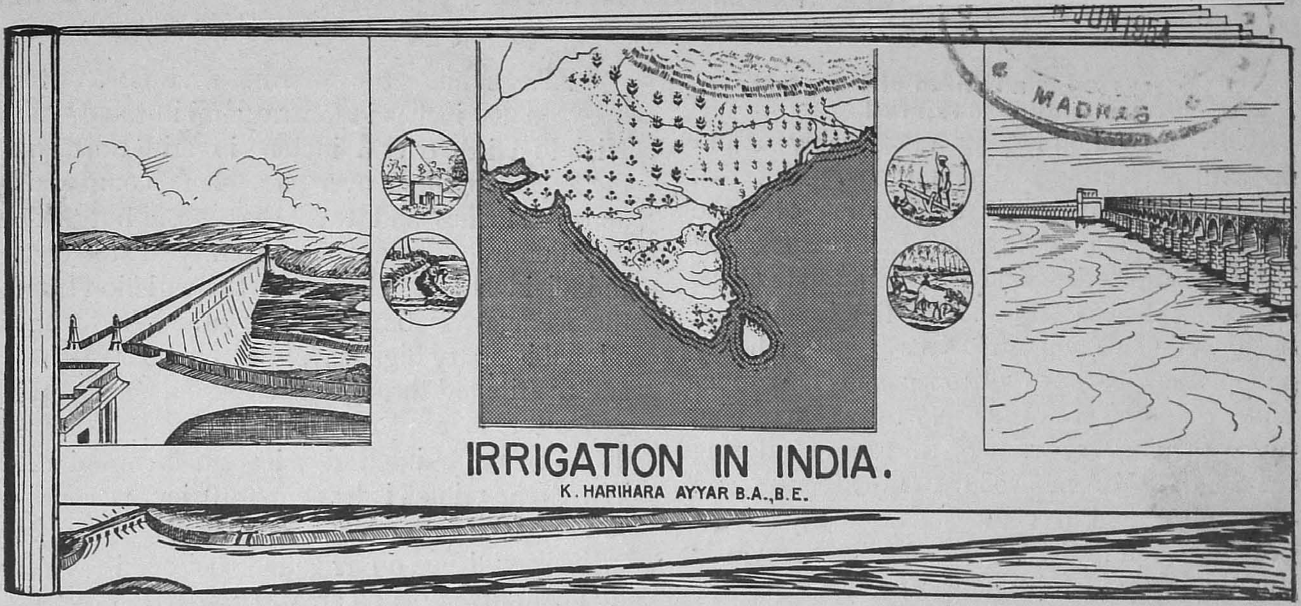
A spillway bridge consisting of Nine spans of 36′ each with a width of 25′–3″ to accommodate a 22′ roadway between parapets had to be built on a dam. The intermediate masonry piers were nine feet thick. The design provided for a 'T' beam and slab bridge supported on four beams. The beams and the slab had to be cast at a height of nearly 150′ above the river bed and thirty five feet over the spillway in the dam. The ogee curve of the spillway would not permit of a satisfactory resting of the supports for the centering. The weight of reinforced concrete in the 'T' beam and the slab worked out to about Eight tons and the live load, another four tons. Besides the routine materials required for the work, some 35′–6″ long R. S. beams of size 18″ x 6″ and ordinary mild steel sections of smaller dimensions were also available at site. Actually the 'T' beam and slab were built, adopting a method (which may not necessarily be the only method of execution of such a work), and this will be described in the next issue.

Readers may in the meanwhile send in what they consider to be suitable design for the centering and support for a bridge of the above description, keeping in mind the fact that the cost of this centering should be the minimum possible so as not to increase the overall cost of the works including the superstructure.

IN these difficult days, the way to progress and prosperity lies in thinking good and constructive thoughts and working together in harmony to achieve a good and common object. The democratic form of Government helps to achieve this provided all of us think constructively, sink our egos, and give a bit away of our own individual selves and work together. The difference between democratic Government and other absolute forms of Government lies in this willingness of each one of us to surrender voluntarily a part of his rights and privileges for the benefit of others so that co-ordination, orderly and harmonious work will be possible. It is not the type of militant union of a group of men who bargain with the rest of society and try to get more for themselves and often more than what they give. This would be violence in thought and action, violence to other groups of men. What is needed is a non-violent union of men, inspired by non-violent Gandhian ideals, determinded to work hard and make the world progress as fast as the science is progressing.

IT is in the above sense that I appeal to brother Engineers to develop the team spirit in them, think and work without violence in thought and deed, imbued by ideals which will make for the good of the country and the world. Free exchange of knowledge, willingness to impart this to others and not make a secret of it, help and work jointly with others, are some of the ways in which the good of this country can be achieved.

Special Chief Engineer, Irrigation.



IRRIGATION IN INDIA.

K. HARIHARA AYYAR B.A., B.E.

[***Introduction*** :—Beginning from this issue, a series of articles on the History of "Irrigation in India", will be published. They were written by Sri K. Harihara Iyer, B.A., B.E., (now Deputy Chief Engineer-General, Buildings & Public Health) on a requisition from the Tamil Lexicon Authorities and sent to them for translation and publication in the Tamil Encyclopedia.

The articles deal with the progress of Irrigation from the distant past and chronicle the stages of evolution of Irrigation from its inception to the present day. Sources of irrigation, volume of water available and distribution systems, have been analysed in this compendium in an interesting and comprehensive manner.

The first series deals with the necessity for Irrigation, the characteristics of the country's terrain, the system of natural River flows obtaining therein and discusses the available Rainfall intensity which is a fundamental requisite for Irrigation.]

1. Necessity for Irrigation

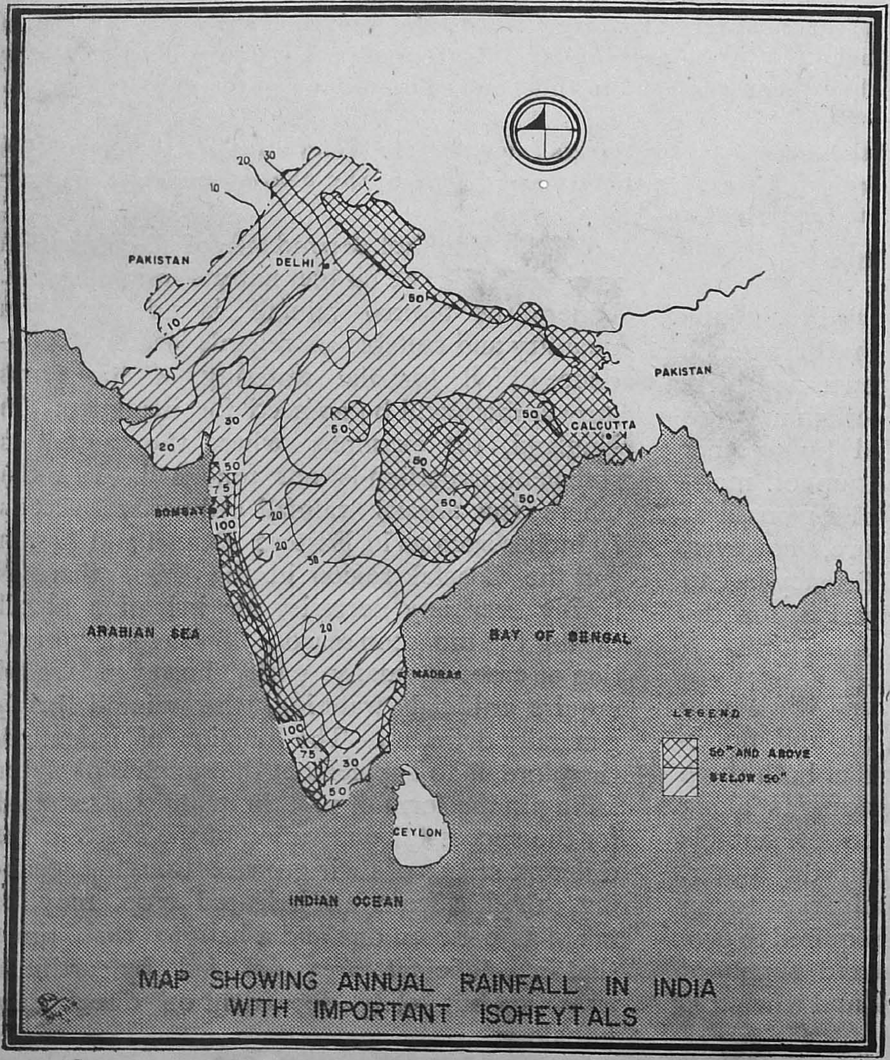
1.1. Irrigation is the science and technique of feeding lands with water with the specific object of nourishing the crops grown on them. Crops require for their growth a certain measure of heat and light generally afforded by weather conditions and an optimum quantum of moisture. In the tropical and subtropical regions, heat and light are abundant; Moisture, however, is frequently deficient and the deficiency has to be made good artificially by irrigation, for the crops to grow up to their full stature.

1.2. Natural irrigation occurs when rain falls or a river spills over its margin and floods the lands in its vicinity. Very often, both these are controlled by forming embankments along the rivers and by the construction of suitable bunds around the fields to retain the water. These form the necessary preliminaries to an integrated system of irrigation, required to give effect to a controlled and regulated supply of water from a river to the crops as and when it is needed.

1.3. The first dependence of all cultivation may be said to be on the natural rainfall only. Where the normal rainfall is adequate in quantity and suitable as regards seasonal incidence of fall for the watering of the crops grown, there will be no need for irrigation. In England, for example, where the rainfall is sufficient, irrigation is not practised. In India where the annual rainfall ordinarily exceeds 70 inches such as in Eastern Bengal and Assam and the Coastal region in the West there is hardly ever any necessity for irrigation at all during the monsoon season. Successful cultivation of crops in many parts, however, would require artificial watering, the rainfall being generally deficient. The function of irrigation, therefore, is to supplement the supplies of water falling in the form of rain in quantities required for the successful cultivation of the crops in the different stages of their growth. Roughly speaking, the yield from an irrigated crop, may be taken as between one and a half to three times that in a deficient area not fed by artificial irrigation but solely dependent on direct rainfall alone.

2. Areas in India in need of Irrigation in relation to rainfall

2.1. Irrigation is thus inextricably bound up with meteorological conditions. In India, the rainfall is unequal in distribution over the country, irregular throughout the seasons and liable to serious deficiency or even total failure. Except in the coastal region in the South-East of the peninsula which receives a rather heavy precipitation between October and December under the influence of the Northeast monsoon, by far the greater portion of the rain falls during the South-West monsoon between June and September and is copious particularly in the coastal region in the West. During the winter months the rainfall is comparatively small while the hot weather from March to May is practically rainless, although a few thunderstorms during this season are not uncommon in some parts.



MAP SHOWING ANNUAL RAINFALL IN INDIA WITH IMPORTANT ISOHEYTALS

Fig. 1 (Vide para 2.2).

2.2. While the normal rainfall varies between 460 inches in Cherrapunji in the Assam Hills to a little over 3 inches in arid Rajastan, the average rainfall over the whole country is about 42 inches and there has been but little variation from this average from year to year. In individual tracts, however, the variation from the average has been very great. Where the rainfall is pretty high, say, well above 50 inches and distributed through the season, successful agriculture is rendered possible by the abundance of the rainfall despite small variations. Where the rainfall is less than 10 inches, cultivation would be possible only through almost exclusive reliance on irrigation. Tracts like Sind are illustrative of such areas. (Fig. 1).

2.3. Generally speaking, it may be said that the areas which lie within the 50 inches rainfall isohyetal stand in need of irrigation. Within this belt is situated the high-lying central rocky plateau which forms the interior of the peninsula. An uncertain rainfall causes rivers in this area to be practically dry for most of the year although they swell up sometimes for short periods during the monsoons. A scanty population with little agricultural activity as compared with that which flourishes in the alluvial tracts is a natural sequence of the unfavourable circumstances in which this region is placed. No doubt a few reservoirs have been constructed here to conserve heavy monsoon rainfalls and extend its benefits over the other seasons. These works being few and far between and as the resources are also limited, it would appear that by far the greater portion of this plateau is destined to remain for ever unirrigated for want of water.

2.4. Excluding this central plateau, the precarious areas which have a normal rainfall of less than 50 inches and which stand badly in

need of irrigation, cover the Punjab, Uttar Pradesh except the Submontane districts, a large portion of Bihar, portions of Madhya Pradesh and Orissa and most of Bombay and Madras States except a narrow strip along the West Coast. It is in these areas that the great irrigation systems in India have been constructed.

3. All Sources of Irrigation have rain as their origin

3.1. All sources of irrigation, can ultimately be traced back to rain, as their origin. It is rain that soaks into the ground and gives a never-failing supply in the form of an under-ground reservoir, from which water is tapped through wells and utilised for irrigation. The sub-soil water is held in place by the presence of an impervious stratum below it. This retentive substratum is nothing but rock or consolidated sodium-clay hardened by heat in the interior of the earth. The sub-soil water is not stationery but has a gentle flow towards the valleys.

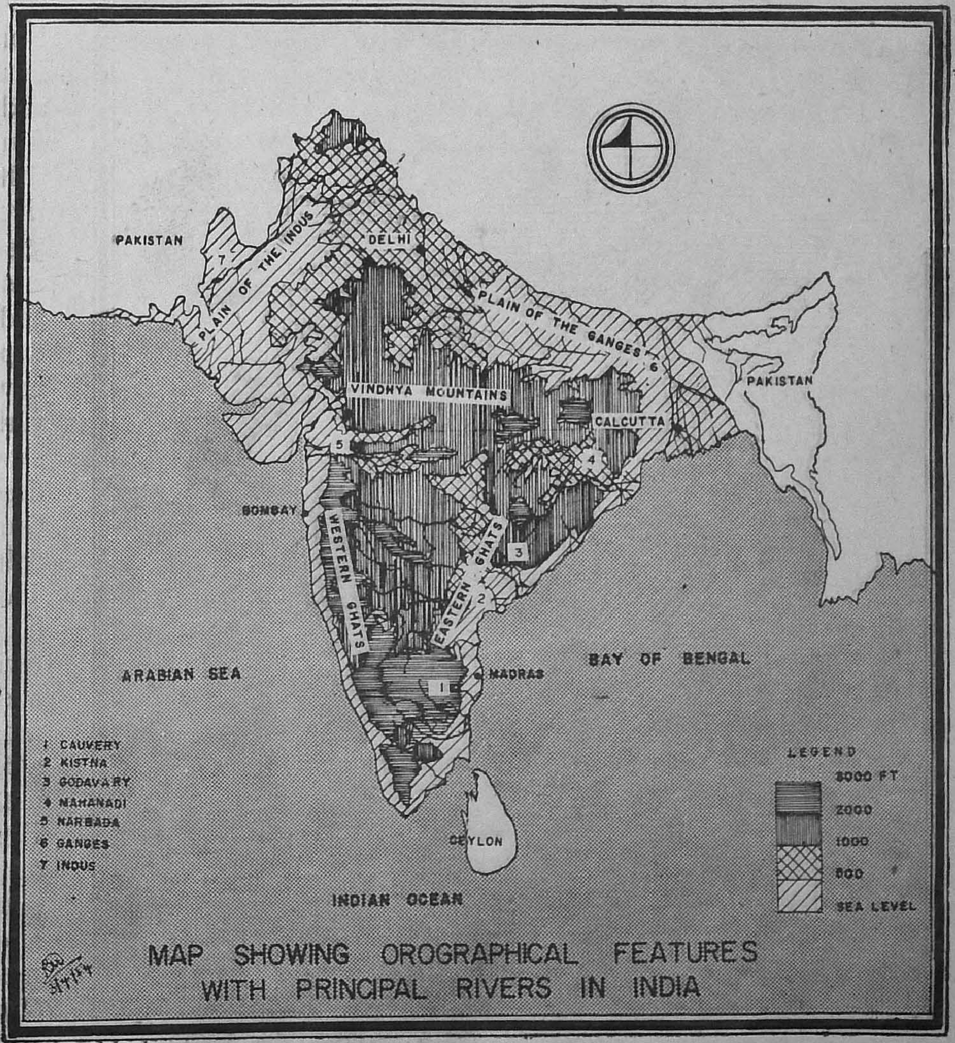
3.2. It is rain again that flows down the several valleys in rivers and streams that traverse the country and from which water is diverted for irrigation.

4. Rivers in India.

4.1. The rivers in India can be grouped broadly under two classes (1) The Peninsular rivers and (2) The Himalayan Rivers. (Fig. 2).

4.2. The Peninsular rivers rise in the Western ghats, almost within sight of the Arabian Sea. The Chief rivers of the Peninsula flowing in the easterly direction and discharging their waters into the Bay of Bengal, are the Mahanadi, the Godavari, the Kistna and the Cauvery all of which have built up vast deltas at their outfalls into the Sea. The Narbada and the Thapti flow towards the West, due, it is believed, to the land to the west of the ghats having faulted down into the sea.

4.3. The rivers in the north of the Peninsula rise from the Aravallies and the Central India highlands and join the Gangetic system. The Aravallies act as a water-shed separating the westerly from the easterly flowing drainages, while the Vindhyas and Satpuras separate the northerly from the southerly flowing drainages. The Chambal, Betwa and Sone drain the northern edges of the Peninsula.

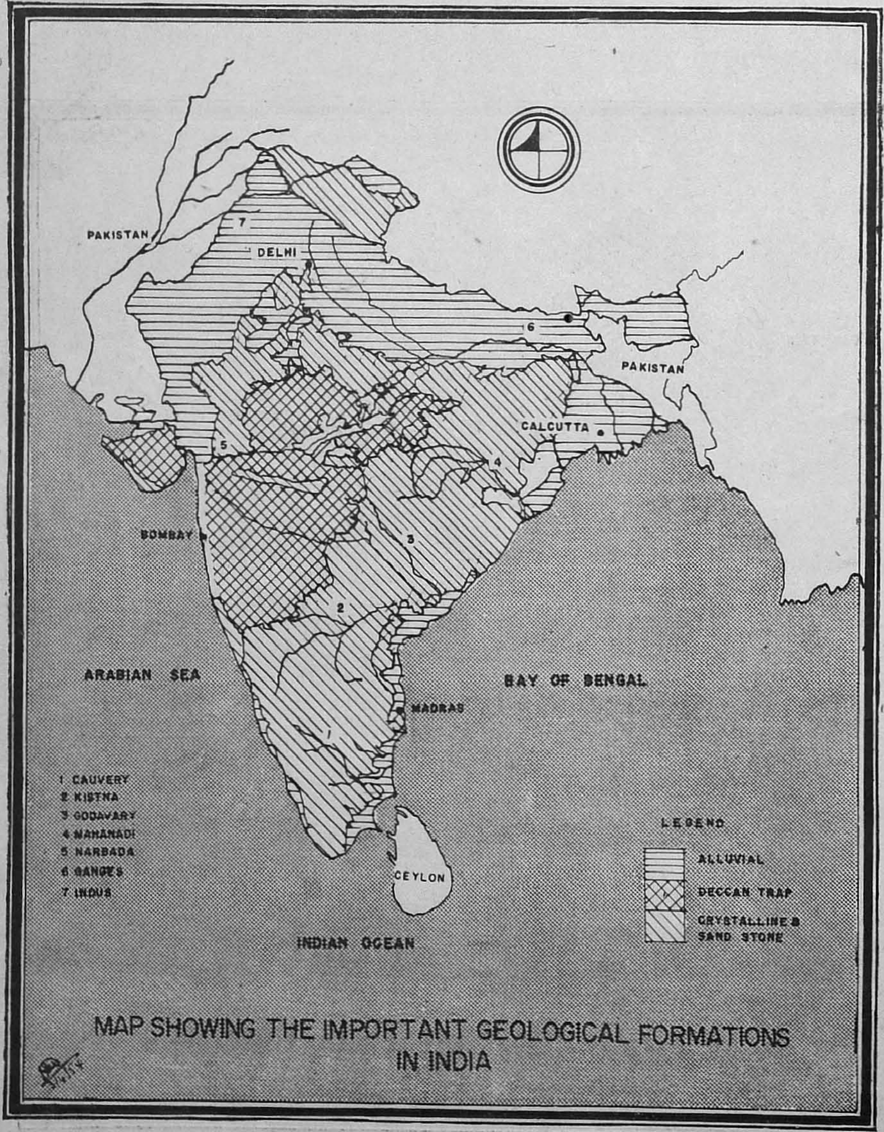


MAP SHOWING OROGRAPHICAL FEATURES WITH PRINCIPAL RIVERS IN INDIA

Fig. 2.

4.4.1. The Himalayan rivers could be grouped under three heads: (1) The Indus system; (2) The Ganga system and (3) The Brahmaputra system. There are 22 important rivers making up these systems flowing through deep and steep gorges in the mountains but with low gradients, on reaching the plains.

4.4.2. The Indus system comprises the Indus, Jhelum, Chenab, Ravi, Beas and Sutlej, the Gangetic system comprises the Ganga, Yamuna, Sarada, Ramganga, Kosi etc. and their several tributaries and the Brahmaputra system includes the Brahmaputra, Tista, the rivers of Bhutan, the Subanseri, Dibang and Lubit.



MAP SHOWING THE IMPORTANT GEOLOGICAL FORMATIONS IN INDIA

Fig. 3.

4.4.3. The Brahmaputra flows through the Assam valley which is favoured by Nature with a good precipitation of rainfall and hence does not stand in need of any irrigation at all. But the Indus and the Ganga systems have been exploited for the benefit of irrigation by the construction of innumerable number of Canals in the Indo-Gangetic plains.

5. Characteristics of Cultivated Soils in India

5.1. Being interlinked with agriculture, no review of irrigation would be complete without a correlated study of the characteristics of the cultivated soils. In India, the principal geological divisions are the alluvial tracts, the Deccan trap and the crystaline and the sand-stone formation. (Figure 3).

5.2. The alluvial tracts cover the greater part of Northern India from the Himalayas to the Vindhyas and extends in a narrow fringe round the coast in the deltaic tracts of the Peninsular rivers. In the Gangetic plain, the sub-strata generally consits of alternate layers of sand and clay extending to great depths. The surface soil, however, shows an infinite variety from the wind blown sands of the Rajaputana desert to the rich loam of the Ganges valley and of the deltas of the eastern coast. The alluvial plains absorb a large percentage of rainfall owing to their small declivity and, in consequence, wells in most parts of this region give a copious supply. These plains are traversed by the great Himalayan rivers which hold an inexhaustible store at the source in the shape of glaciers and snow which conveniently melt in summer and give an abundance of supply which man can never hope to rival with all the ingenious methods

he has evolved for artificial storage of water. It is this special feature of these rivers which enables them to give supplies in summer for the benefit of irrigation far in excess of the normal flows in them during the other seasons that makes them stand out in striking contrast to the Peninsular rivers most of which run practically dry in the hot weather. This measure of Nature's bounty coupled with the facilities, the alluvial tracts afford for development of irrigation has attracted the early Irrigation Engineers and this explains why most of the great canal systems in India have been built in this region. The gentle gradients of these great rivers in the alluvial tracts have also made it comparatively easy to distribute the water over the fields for irrigation.

5.3. The trap formation, covers an area of some 2,00,000 million sq. miles in Central India, Bombay, Madhya Pradesh and Hyderabad. The surface is broken and uneven. The soil generally contracts due to the heat of the sun and cracks develop extending sometimes to several feet in depth. Irrigation is not generally suited to the black cotton soils which are found in some parts of these tracts where the substrata afford but little facility for natural drainage, even though the soil may be rich in fertility. The irrigated extent forms a very small fraction of the total area under crops in these parts being as low as 3 to 4 per cent.

5.4. The crystalline and sand-stone formation may be said to extend over the whole of Madras and large portions of Bengal. The prevailing soils vary from a dark red loam to light sandy soils. Some of the better class of these soils are not inferior in fertility to the loamy soil of the alluvial tracts. The peninsular rivers which rise in the Western ghats and traverse this tract have deep channels although their gradients are small. The topographical features preclude the utilisation of the waters beyond the narrow confines of their valleys. In the areas beyond their command there are many tanks which collect the rainfall. The broken and undulating nature of the country facilitates their construction, but renders the distribution of water rather difficult.

Design of Retaining Walls

Retaining walls may be broadly classified as (1) Low retaining walls upto heights, say 30 or 35 ft. and (2) High retaining walls with heights exceeding 35 ft.

As regards Low retaining walls which have been hitherto mostly adopted in Irrigation practice, the design based on rules of thumb has been found to be satisfactory; though sections with base widths as low as 1/4 to 1/3 H have been adopted in some cases, even these walls have stood without a portion of the wall breaking off from the rest of it and falling away.

An important factor which has been overlooked by many designers in the past is the toe pressure on the soil. It has been stated that 99 per cent of the failures of the retaining walls have been due to the failure of the foundation soil. The best working method should give a section which experience has shown to be satisfactory and should at the same time enable us to compute the toe pressures on the soil without exaggeration.

Based on the above practice, for walls upto 30 ft. in height, the section may be as given in Figure 1.

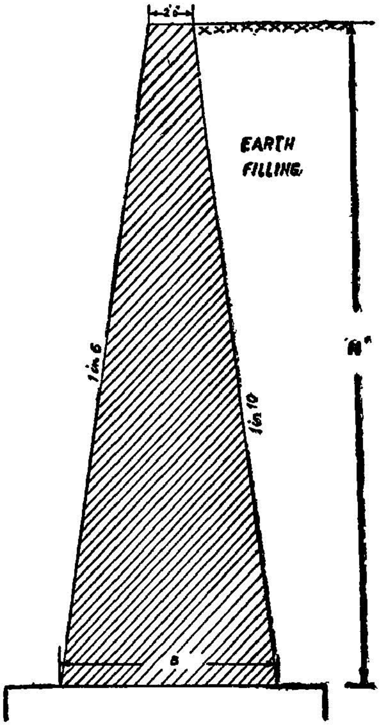


Figure 1.

Base width for heights upto 30 ft.

B = 2 plus H/6 plus H/10 = 2 plus 0.26 H.

For a wall of 30 ft. height this gives a base width of 2 plus 8 or 10 ft. This width of 10 ft. works out to 10/30 or 0.33 H. For walls upto 30 ft. in height there is no case for adopting a base width greater than 1/3 H. The batter on the outer (exposed face) may vary from 1 in 12 to 1 in 6, the balance of batter being thrown in on the earth face.

It is interesting to observe in this connection that the great batter on the earth face does not affect the stability detrimentally, as in such cases, the earth standing on the wall slope is considered as acting with and forming part of the wall. (See Appendix 2).

Though the wall section suggested above is suitable so far as the wall goes, the foundation has to be suitably designed in each case to suit the maximum safe pressure on the soil. For example, in gravelly soil a foundation as shown in Fig. 2 will be sufficient; but in poorer soils as met with in aqueduct at 92/3 of Tungabhadra Project the foundation has to be spread out to bring the resultant as near the centre of the base as possible as shown in Figure 3.

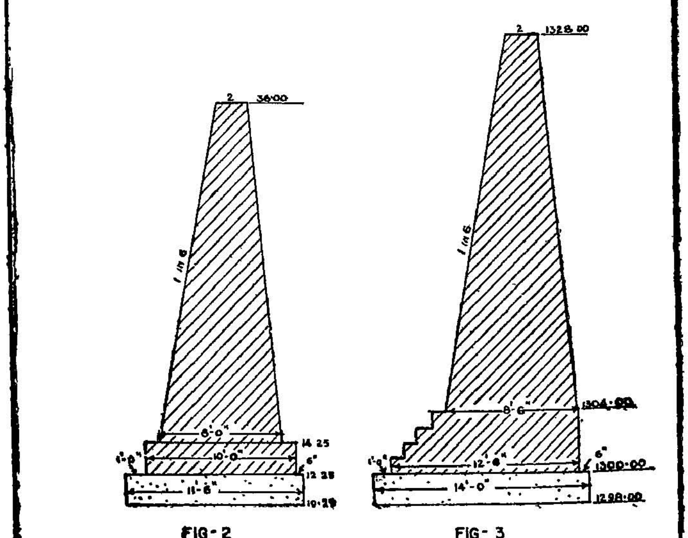


FIG-2 FIG-3

RESULTANT MAXIMUM PRESSURE 1.5 TONS/SQ.FT IN EACH CASE

In the case of high retaining walls the stresses in the masonry and toe pressures on the foundations increase rapidly and sections given above for walls upto 30 ft. in height are unsuitable.

For walls 30' to 40' in height the base width may gradually increase from 0.33 H to 0.40 H; for walls 40 to 50 ft. in height the base width may gradually increase from 0.40 H to 0.50 H with top width of 3 ft.

In very high retaining walls—say walls over 50 ft. in height, considerable care is required in design. Most of the batter has necessarily to be thrown on the outside and earth side batter may be as small as possible to secure maximum economy. A batter from 1 in 10 to 1 in 12 may perhaps be sufficient.

In these high structures, of primary importance is the determination of earth pressure to be carried. Unless the pressure computed is as far as possible nearer the actual there will be great error creeping into the calculations and resulting in wasteful design. Though various theories are in vogue for determining the pressure, the Coloumb's theory is held by modern designers to be the best available for general design purposes. The reason for favouring this theory is the series of investigations and experiments described by Mr. Terzaghi in the Engineering News Record from February to May '34, which have amply substantiated this theory.

Terzaghi's experiments have shown that the centre of pressure of the earth thrust may vary considerably. A loose fill may compare with conditions of fluid pressure in that its centre of pressure will be about 1/3 H above base. Compaction of the particles will develop some 'arch' action in the fill and raise the centre of pressure to as much as 0.42 H. For design purposes it would suffice if P is assumed to act at 0.40 H above the base, except in special cases of surcharge. The determination of pressure requires that values be known for the following factors:—

(1) Weight of fill

(2) Angle of internal friction of fill

(3) Angle of friction between fill and retaining structure; and

(4) Angle between surface of fill and a horizontal plane. These values may have to be predetermined in a soil laboratory and for high retaining walls, it is imperative that these are accurately determined, before computing the earth pressure.

Where the back fill is saturated, provision of drainage has to be considered for control or minimising the effect of saturation. The drains should be designed with liberal dimensions and must be constructed with care.

For walls over 100 ft. in height the minimum base width may be taken as about 60 per cent height and the maximum as 2/3 H which may be the upper limit in any case.

The following is a summary of the above.

No.	Height of Retaining Wall (H)	Recommended Base Width for a top width of 3'
1	Less than 30 feet	.33 H*
2	30 feet to 40 feet	.33 H to .40 H
3	40 feet to 50 feet	.4 H to .5 H
4	50 feet to 100 feet	.5 H to .6 H
5	Above 100 feet	.6 H to .66 H

* In this case the top width is only 2 feet.

The T. V. A. in America have also adopted designs for retaining walls based upon the qualified verification of Terzaghi's experiments and these principles of design given in their Hand Book may be taken for guidance. Salient features and curves are furnished in Appendices (1), (2) and (3). But the designer's commonsense and practical judgment have also to be exercised in arriving at the most economical and suitable section required in a particular locality.

APPENDIX 1.

Design of Retaining Walls—T. V. A. Procedure.

I. Dr. Karl Terzaghi's classical experiments on high retaining walls detailed in Engineering News Record (1934) have indicated that the pressure behind retaining walls closely approximates to that given by Coloumb's Wedge Theory and that it acts at 0.40 H from the base and in a direction inclined to the back of the wall.

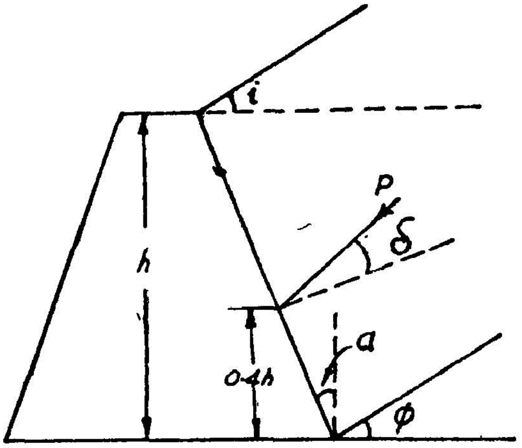


Figure 4.

$$P = \frac{wh^2}{2}\left[\frac{\cos(\phi-n)}{(1+n)\cos a}\right]^2 \times \frac{1}{\cos(a+\delta)}$$

where

$$n = \sqrt{\frac{\sin(\phi+\delta)}{\cos(a+\delta)}\frac{\sin(\phi-i)}{\cos(a-i)}}$$

P=pressure in lbs.

h=height of fill at the back of the wall

w=weight of fill in lbs/cft.

ϕ=angle of internal friction

δ=angle of friction between fill and wall face.

i=angle between surface of fill and a horizontal plane

a=inclination of wall face to the vertical

If $i=0$, $\delta=0$, $a=0$ the formula reduces to

$$P = \frac{wh^2}{2}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)$$

II. For the usual roller fill $\phi=32°$

The angle of friction against wall

$\delta=\phi/2=16°$

w=105 lbs/cft if fill is of sand or gravel, but w=120 lbs/cft if of finer material.

III. The batter of the back should be as small as possible to secure maximum economy. In fact from this stand point a should have a negative value (*i.e.*) the structure should overhang. But in important structures where contact between the wall and earth should be perfect to prevent passage of water, it is advisable to use an earth face batter of 1 in 12 (a=4°46'). But when the fill is of permeable material, this contact value is not of much importance and a can even be made zero, that is, the back of the wall will be vertical.

IV. *Walls with large back batters:*—Conditions other than wall economy sometimes require that the back batter of a wall depart materially from the vertical. In such cases a portion of the earth on the wall slope moves along with the wall at the time of failure and no sliding of earth on wall takes place; in fact in this case sliding of earth on earth takes place and a second plane of rupture forms under these conditions. In T.V.A. practice the Coloumb theory is used for such walls but with a reduction of the normal margins of safety. For walls with back batter of 4:12 or 1 in 3 or less, the walls shall have no tension at the foundation (*i.e.*) the eccentricity of the resultant shall not be more than 1/6 base width. With batter of 6:12 or 1 in 2 an eccentricity upto 1/4 base width is allowed and for intermediate batters the permissible eccentricities are found by interpolation. An additional requirement in walls having a back batter greater than 1 in 3 is that overturning ratio shall not exceed 1.75.

V. *Saturated fill:*—In many cases connected with the design of hydraulic structures the earth behind the wall gets partly or totally saturated. In this case the following procedure has been adopted:

(1) The hydraulic pressure below the point of saturation is determined as though no fill were present.

(2) The earth pressure resulting from the buoyant weight of the fill (65 lbs/cft) is calculated using the same values of ϕ and δ as would be used if the fill were dry. These two forces are combined in quantity and moment to produce a resultant earth pressure on the walls.

VI. *Calculation of fill pressures:*—

$$I = Kwh^2 \text{ where } K = \frac{1}{2}\left\{\frac{\cos(\phi-a)}{(1+n)\cos a}\right\}^2 \frac{1}{\cos(a+\delta)}$$

and the horizontal and vertical components are given by

$P_H = K_H\, wh^2$ where $K_H = K\cos(a+\delta)$

$P_V = K_V\, wh^2$ where $K_V = K\sin(a+\delta)$

These formulae can be used to compute the pressure from a drained fill with any value of i, or from a fully saturated fill with level surface. In the latter case W_1 (65 lbs/cft), of course, replaces w (120 lbs/cft).

P_H and P_V shall be assumed to act at 0.4h above the base of the wall. The water pressure of the saturated fill acts, of course at 0.33h.

The table below gives values of K_H and K_V for usual values of ϕ and α. For level fills use the test for $i = 0$.

TABLE OF EARTH PRESSURE CONTENTS (T. V. A. DESIGN BOOK)

ϕ	δ	i	α	K_H	K_V
32°	16°	0°	0° (vertl.)	0.134	0.038
			40°46′ (1 in 12)	.146	.055
			18°26′ (1 in 3)	.180	.123
		18°26′	Vertical	.174	.050
			1 in 12	.193	.073
			1 in 3	.246	.169
32°	28°	0°	Vertical	.121	.065
			1 in 12	.131	.085
			1 in 3	.155	.163
		18°26′	Vertical	.161	.086
			1 in 12	.177	.114
			1 in 3	.221	.232
38°	19°	0°	Vertical	.103	.035
			1 in 12	.115	.051
			1 in 3	.148	.113
		18°26′	Vertical	.128	.044
			1 in 12	.144	.064
			1 in 3	.194	.148
38°	28°	0°	Vertical	.096	.051
			1 in 12	.107	.069
			1 in 3	.132	.139
		18°26′	Vertical	.121	.064
			1 in 12	.136	.088
			1 in 3	.178	.187

$P = \frac{1}{2} Cwh^2 = Kwh^2$ where $K = \frac{1}{2}C$ and the above values are for 'K'

Stepped back:—In dealing with gravity walls with stepped back the T.V.A. procedure is to pass a vertical plane through the end of the section and to determine the earth pressure against the imaginary vertical plane. The weight of the fill between the plane and the wall is to be included with the weight of the wall. In this case the wall friction δ shall usually be replaced by ϕ the internal friction of the fill. In the case of a stepped wall with a pressure on the vertical plane, partly against concrete and partly against earth, a satisfactory approximation is to use $\delta = 28°$ for the combined section.

If a wall has two or more back batters for example 1:12 for the top, changes to 1:4 near the bottom, the pressure may be adequately determined by substituting an approximate average batter. Such approximation is usually sufficient and within the limits of accuracy of any determination of earth pressure.

Ref:—T.V.A. Design Hand Book.

APPENDIX 2.

Choice of Batters in Retaining Walls.

The object is to find out how best the material could be placed to obtain the maximum

safety or factor of safety for the wall *i.e.*, the discussion will be restricted to several types of walls, all having the same quantity of material *i.e.*, the same top width and base width for a given height. The discussion is confined to the methods of analysis recommended in Merriman and Wiggins' Civil Engineers' Hand Book.

2. After consideration of all the theories of earth pressure the authors recommend on page 896 of the book

(*a*) the earth pressure may in all cases be considered to be horizontal.

(*b*) The weight of the earth standing on the back of the wall should be regarded as part of the wall.

It should however be mentioned in passing that these assumptions have not been supported by the results of the earlier experiments or by those of the latter authorities in the field like, Dr. Karl Terzaghi.

3. As regards the value of earth pressure he recommends $P = \frac{wh^2}{2} \cdot \frac{1 - \sin\phi}{1 + \sin\phi}$ and takes it as acting at 1/3 height from the base in a horizontal direction. This form and value is similar to liquid pressure.

4. For the initial discussions for the sake of simplicity let us confine ourselves to a triangular profile.

Let us take two profiles: (*a*) one with all the batter on the earth face and (*b*) another with all the batter on the outer face.

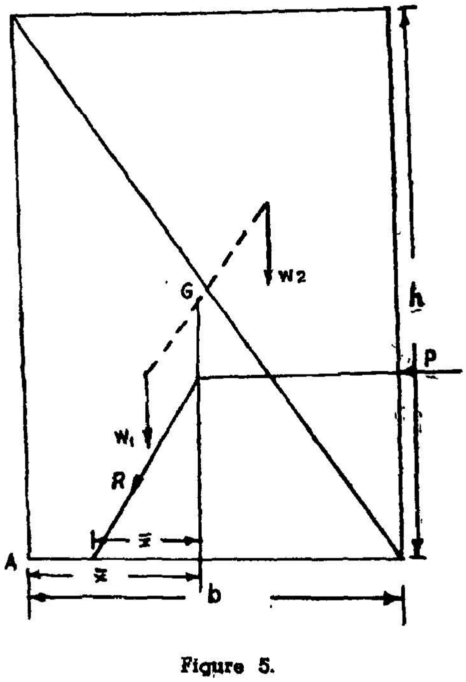


Figure 5.

Let us take the weight of earth as 112 lbs/cft of masonry as 140 lbs/cft and ϕ as 33°—24′ (1½:1). Then

$$\frac{1-\sin\phi}{1+\sin\phi} = \frac{2}{7} \text{ and } P = \frac{112 \times 2}{7} \frac{h^2}{2} \text{lbs.} = 16\,h^2 \text{ lbs.} \quad (1)$$

$$\text{Weight of wall } W_1 = \frac{bh}{2} \times 140 = 70\,bh \text{ lbs.} \quad (2)$$

Weight of earth standing on wall

$$W_2 = \frac{bh}{2} \times 112 = 56\,bh \text{ lbs.} \quad (3)$$

Overturning moment (*i.e.* moment of earth pressure)

$$= P\,\frac{h}{3} = 16\,h^2 \times \frac{h}{3} = 5\tfrac{1}{3}h^3$$

Resisting moment in case I:

$$W_1 \times \frac{b}{3} + W_2 \times \frac{2b}{3}$$

$$= \frac{70\,bh \cdot b}{3} + \frac{56\,bh \cdot 2b}{3} = \frac{b^2h}{3} \times 182 = 60\tfrac{2}{3}\,b^2h \quad (4)$$

Resisting moment in Case II:

$$W_1 \times \frac{2b}{3} = \frac{70\,b^2h \times 2}{3}$$

$$= 46\tfrac{2}{3}\,b^2h \quad (5)$$

It is clear from the above analysis that if stability against overturning were the sole criterion in the design of retaining walls it will be definitely an advantage to throw all the batter on the earth face.

Let us now pause for a moment and examine the stability of the walls from other considerations, for example the stresses developed in the masonry.

To find the stresses developed we have first to find the position of the resultant.

In (I), the resultant weight acts at a distant $\bar{x}$ from A, given by

$$\bar{x} = \frac{W_1 x_1 + W_2 x_2}{W_1 + W_2} = \frac{60\tfrac{2}{3}\,b^2h}{126\,bh} = 0.4815\,b$$

for $\bar{Z}$, we have $126\,bh \cdot \bar{z} = \frac{16h^3}{3}$

$$\text{or } \bar{Z} = \frac{16}{3 \times 126} \times \frac{h^2}{b} = 0.0423\,\frac{h^2}{b}$$

∴ distance from edge

$$e_1 = \bar{x} - \bar{Z} = 0.4815b - 0.0423\frac{h^2}{b}$$

In (II) $\bar{x} = 2/3\,b = 0.6667\,b$.

$\bar{Z}$ is given by $\frac{16\,h^3}{3} = 70\,bh.\,\bar{z}$

$$\text{or } \bar{Z} = \frac{16}{210}\,\frac{h^2}{b} = 0.0762\,h^2/b$$

∴ distance from edge

$e_2 = \bar{x} - \bar{Z} = 0.6667\ b - 0.0762\ h^2/b$

Taking a base width of 0.4 h we get

$e_1 = 0.4815\ b - 0.2644\ b = 0.2271\ b.$

$e_2 = 0.6667\ b - 0.4762\ b = 0.1905\ b.$

Maximum stress in (I) $f_1 = \frac{QW}{3e} = \frac{252\ bh}{0.6813\ b} = 370\ h$

Maximum stress in (II) $f_2 = \frac{140\ bh}{0.5715b} = 245\ h$

i.e. the stresses in the masonry are 50 per cent more in Section (I) than in Section (II). The above results are in conformity with the values in Table (F) on p 916 of Merriman and Wiggins. It is clear from the above that throwing all the batter on the earth face does not result in an economical section as the stresses developed in the masonry forms one of the main considerations if not the chief one in the design.

5. Let us now examine the sections for a wall case A, 30 ft. in height and case B, 100 ft. height to limit the resultant stresses in the masonry to 18,000 lbs/sq. ft. which is nearly 8 tons/sq. ft.

Case A:—For a 30 ft. wall the base width required are 0.353 h for a wall with earth face batter and 0.36 h for all batter on the outer face

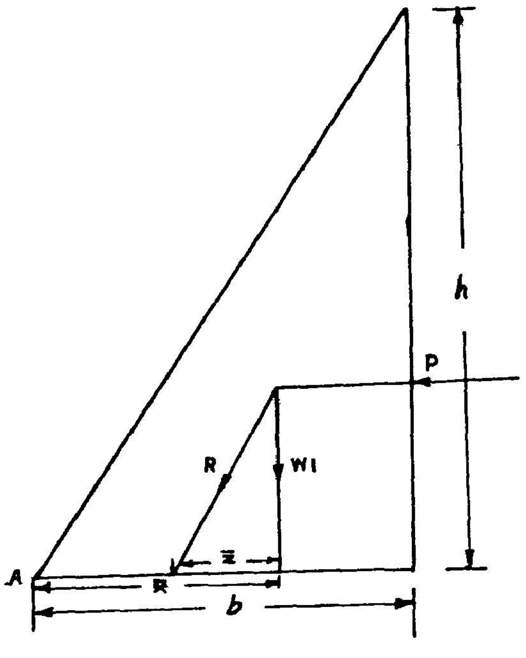


Figure 6.

Alternative I. The outer face vertical and batter in inner face.

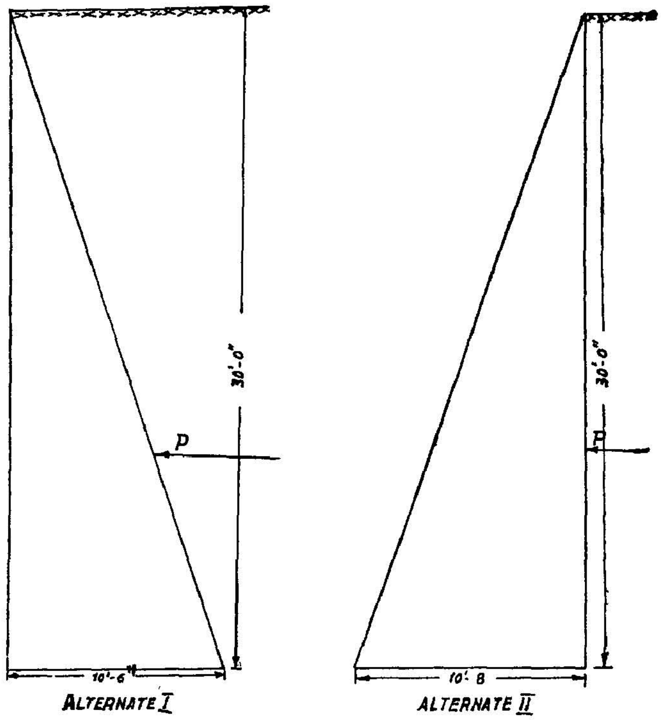


Figure 7.

Weight of wall $= \frac{10'\text{-}6'' \times 30}{2} \times 140 = 22269$ lbs.

Weight of earth $= \frac{10'\text{-}6'' \times 30}{2} \times 112 = 17808$ lbs

Total 40,068 lbs.

Earth pressure = 16 x 30 x 30 = 14400 lbs.

$\bar{X} = 5.10$ $\bar{Z} = 3.59$ ft. e = 1.51

Maximum stress in masonry

$f_1 = \frac{2 \times 40{,}068}{3 \times 1.51} = 17{,}690$ lbs./s. ft.

and the wall has a factor of safety of 1.40 against overturning.

Alternative II: The outer face with batter and inner face plumb.

Weight of wall $= \frac{10.8 \times 30}{2} \times 140 = 22{,}680$ lbs.

Earth pressure = 14,400 lbs.

$\bar{x} = 7.20$ ft. $\bar{Z} = 6.35$ ft. e = 0.85

Maximum stress

$f_2 = \frac{2 \times 22{,}680}{3 \times 0.85} = 17{,}800$ lbs/s. ft.

and the wall has a safety factor of 1.14 against overturning.

The above examination indicates that for Low retaining walls the way the batter is thrown to the front or rear does not affect the stability and resultant stress to any appreciable extent.

Case B:—For a wall with no batter on the outerface the maximum stress in masonry is 362 h and for a wall 100 ft. high this works out to 362 x 100 or 36,200 lbs/s. ft. which is more than double the permissible stress of 18,000 lbs/s. ft. assumed. On the other hand for a wall with all the batter on the outerface of it the stress will be 158 h indicating that even for a 100 ft wall the maximum stress is only 15,800 lbs/s. ft. well within the permissible stress of 18,000 lbs/s. ft.

Maximum stress

$f = \frac{304,500 \times 2}{34.5} =$ 17,650 lbs. *i.e.* below 18,000 lbs.

Factor of safety against overturning

$= \frac{304,500 \times 29}{160,000 \times 33\frac{1}{3}} = 1.66$

In practice the wall may actually be about 50 ft. in base width as shown below. This section will be found to be quite suitable both from the point of view of stresses in masonry and also providing sufficient stability against overturning and sliding.

It will be impossible in this case to design a wall with a vertical or only a nominal batter of 1 in 10 or 12 on the exposed face as will be seen from the analysis given below for such a wall.

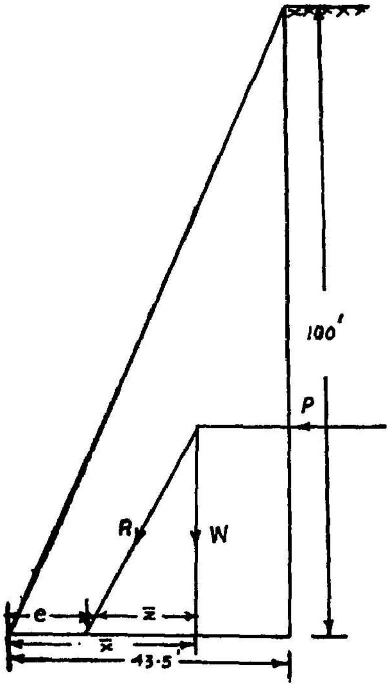


Figure 8.

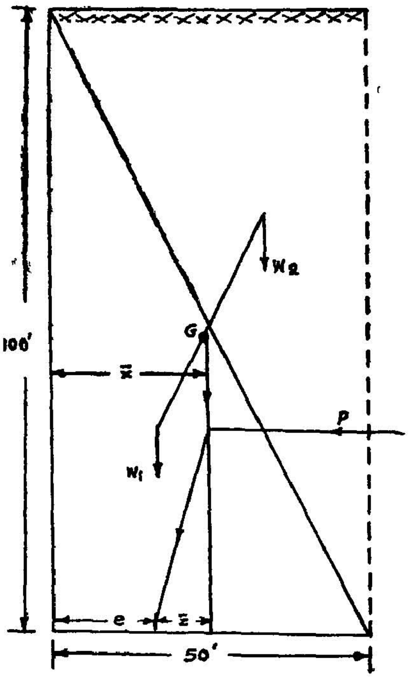


Figure 9.

Assuming a base width of 43½ ft.

Weight of wall $= \frac{100 \times 43\frac{1}{2} \times 140}{2} =$ 304,500 lbs.

Earth pressure = 16 x 100 x 100 = 160,000 lbs.

$\bar{x} = \frac{2}{3} \times 43\frac{1}{2} = 29.0$ ft.

$\bar{z} = \frac{1600}{3045} \times \frac{100}{3} = 17.5$ ft.

e = 29.0 − 17.5 = 11.5

(1) *Base width 50 ft,*

$W_1 = 100 \times 50 \times 140/2 =$ 350,000 lbs.

$W_2 = 100 \times 50 \times 112/2 =$ 280,000 lbs.

$P = 16 \times 100 \times 100 =$ 160,000 lbs.

$$\bar{X} = \frac{350{,}000 \times 50/3 + 280{,}000 \times 100/3}{6{,}30{,}000}$$

$= 24.6$ ft.

$\bar{Z} = 100/3 \times 16/63 = 8.5$ ft.

$\therefore\ e = 24.6 - 8.5 = 16.1$

Maximum stress in masonry

$$= \frac{2W}{3e} = \frac{630{,}000 \times 2}{48.3} = 26{,}100 \text{ lbs/S. ft}$$

which is considerably over the value of 18,000

(2) *Try Base width 80 ft.*

$W_1 = 100 \times 80 \times 140/2 = 560{,}000$ lbs.

$W_2 = 100 \times 80 \times 112/2 = 448{,}000$ lbs.

$$\bar{x} = \frac{560 + 2 \times 448}{1008} \times \frac{50}{3} = 20.8 \text{ ft.}$$

$\bar{Z} = 100/3 \times 16/100.8 = 5.3$ ft.

$e = 20.8 - 5.3 = 15.5$

Maximum stress in masonry

$$= \frac{2016{,}000}{46.5} = 43{,}570 \text{ lbs/s. ft.}$$

Even a 100 ft. basewidth gives maximum stress in masonry of over 10 tons/s. ft.

This indicates clearly that a plumb exposed face with almost all the base width thrown in towards the earth side only tends to increase the stress in masonry very rapidly.

The typical section given below would therefore appear to be best and the most economical section of a 100' retaining wall.

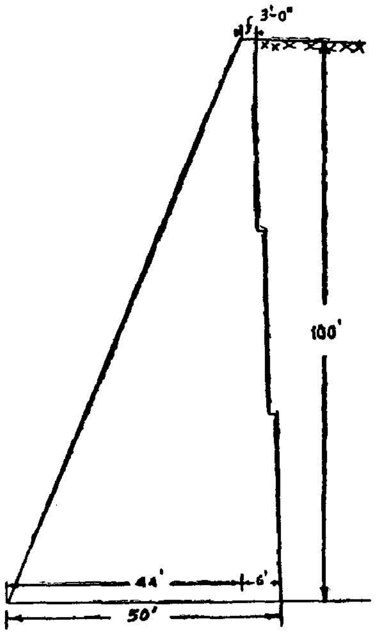


Figure 10.

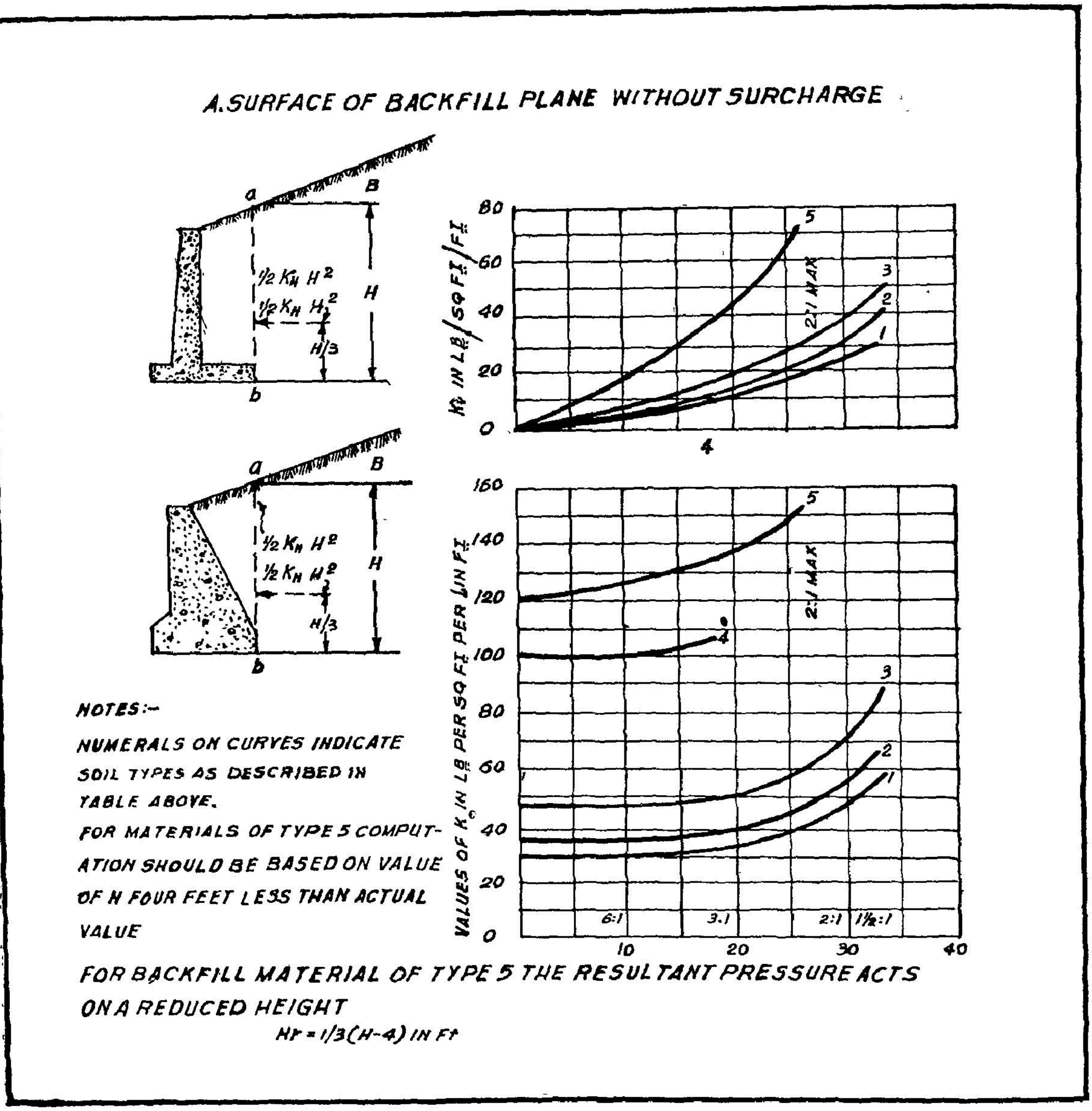
APPENDIX 3.

SEMI-EMPIRICAL METHOD FOR ESTIMATING PRESSURE OF BACKFILL.

Type of Backfill for Retaining Walls

No.	DESCRIPTION OF SOIL.
1.	Coarse grained soil without admixture of fine soil particles permeable (clean sand and gravel).
2.	Coarse grained soil of low permeability due to admixture of particles of silt size.
3.	Residual soil with soil stones, fine silty sand and granular material with conspicuous clay content.
4.	Very soft or soft clay organic silts or silty Clays.
5.	Medium or stiff clay deposited in chunks and protected in such a way that a negligible amount of water enters the spaces between the chunks during floods or heavy rains and if this condition cannot be satisfied the clay should not be used as backfill material as with increasing stiffness of clay, danger to the wall due to infiltration of water increases rapidly.

APPENDIX 3.—(*Continued*).



[*Note*:—Compiled from Circular Memorandum No. 2024/53-A-2 dated 29-7-'53 of the Chief Engineer for Irrigation.]

Five Year Plan in Action

An Irrigation Exhibition to make people "Plan-Minded"

BY SRI T. N. SESHADRI, M.A., M.I.R.E., Aff. Am. Soc. C.E., F. INST. P., F.A.Sc.
Physics and Soil Mechanics Officer.

The Public Works Department of the Madras Government as in the previous years, participated in the All India Khadi, Swadeshi and Industrial Exhibition held at the Tamil Nad Congress Grounds, Teynampet from 22-12-53 to 8-2-54 under approval of the Government in their G.O. No. Ms. No. 4724 P.W.D. dated 22-12-53. This article gives an account of the Departmental stall in this exhibition.

2.1. The general decoration of the stalls and the construction of the in situ models and pedestals, could be started only a couple of days before the opening of the General Exhibition. In order to throw open the exhibition to visitors as early as possible, preliminaries were pushed through expeditiously, working day and night for about 12 to 13 days. On 2-1-54 the stall was in a complete shape for the models to be installed. These models were moved from the Concrete and Soil Research Station at Chepauk to the Exhibition stall on the same day. Within the next forty eight hours, electrical wiring, water supply and other arrangements were completed for all the models to be set in full working order in their proper positions. The exhibition was on view to the Public on 4-1-54 just a fortnight from the start.

2.2. The work on the stall erection, painting and decoration, electrical wiring and lighting were handled departmentally. The completion of this large and intricate construction work within the short space of about 15 days threw a large strain on the staff without whose willing and ready co-operation and hard work, it would not have been possible to achieve so much within so short a time. At least a month's effort would ordinarily be necessary for completing such a work in a systematic and satisfactory manner.

3. The efforts put forth in organising the stall had been amply rewarded considering its popularity with the public who thronged to see the exhibition and partiently waited in unending queues before the stall, specially on holidays, as will be seen from Figure 1 in the Art Supplement.

4. The objects with which the exhibition was organised was nicely summed up by one of the visitors, the President of the District Congress Committee, Bangalore, who recorded his impressions thus; "I congratulate the men in charge of the stall in the excellent arrangement made to show even to a common man the achievements of the Department under the Five Year Plan. The models, charts and other literature were indeed very educative. This is exhibition in its real sense".

5.1. A detailed description of the stall and exhibits is furnished below: A chart showing the arrangement of models and a list of exhibits are given as an annexure to this article.

5.2. On its outside, the stall had a plain and pleasing appearance with the models inside screened effectively. The entrance and exit were at the centre on either side of panel carrying an appropriate painting, with a lotus fountain in front. The panel bore the inscription "*Water Divine Gift to Man*" and a couplet in Tamil.

5.3 The aim of the Irrigation Branch of the Public Works Department in trying to conserve this gift and utilise every drop of it for the general prosperity of the country was graphically brought out thereby.

6.1. The first exhibit on the right, as one entered the exhibition stall, was a Relief model of the Madras State prominently picking up in red, the sites of the Projects showing the " Five Year Plan in Action ". The sites of the other existing Projects and those under investigation were also shown in different colours. A rotary switch arrangement was employed to produce a pleasing sequence in the lighting up of the Project sites.

6.2. The second exhibit was in the nature of a preliminary design for a " Water Level Buzzer " designed and made in the Workshops attached to the Concrete & Soils Laboratory, to automatically signal the water level at a Reservoir or Anicut site to any distant place either through surface telephone or wireless transmission. Considering the urgency of a central authority being kept in constant touch with the fluctuations in water levels, both to decide on equitable regulation of draw off during the irrigation seasons and for taking precautionary measures ahead of floods, it would appear that there are good potentialities for this instrument.

6.3.1. The next exhibit, a large and beautifully got up model of a typical irrigation system was an attractive feature in the left wing of the stall. (Vide Front Cover & Figure No. 2 of Art Supplement). This model, intended to illustrate the constituents of an efficient irrigation system, was set up by the Poondi Irrigation Research Station. A hilly catchment of a river, the sky laden with rain bearing clouds and showers therefrom formed the background to this interesting model. A typical dam was shown right across a valley in the mountainous ranges. The head works included Irrigation sluices, River sluices and a central spillway, as well as a power house for hydro-electric generation.

6.3.2. The main canal taking off from the reservoir, was aligned through a tunnel across a ridge to avoid an uneconomical detour. Cross masonry works such as aqueducts, syphons superpassages, drops and chutes were also incorporated in the model, either on the main canal or on its branches and distributaries, to give a comprehensive picture of a typical irrigation system.

Model of a Typical Irrigation System—Headworks

Five Year Plan in Action

(Art Supplement)

Figure 1.

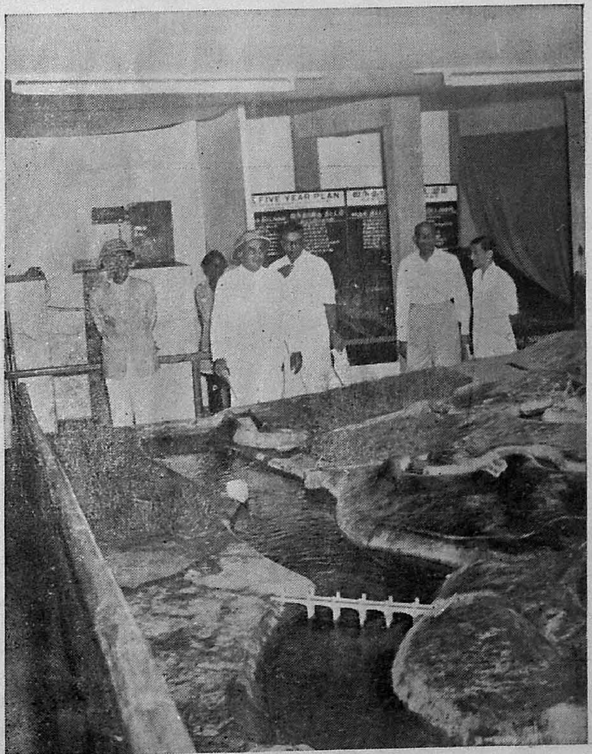


Figure 2.

Figure 3.

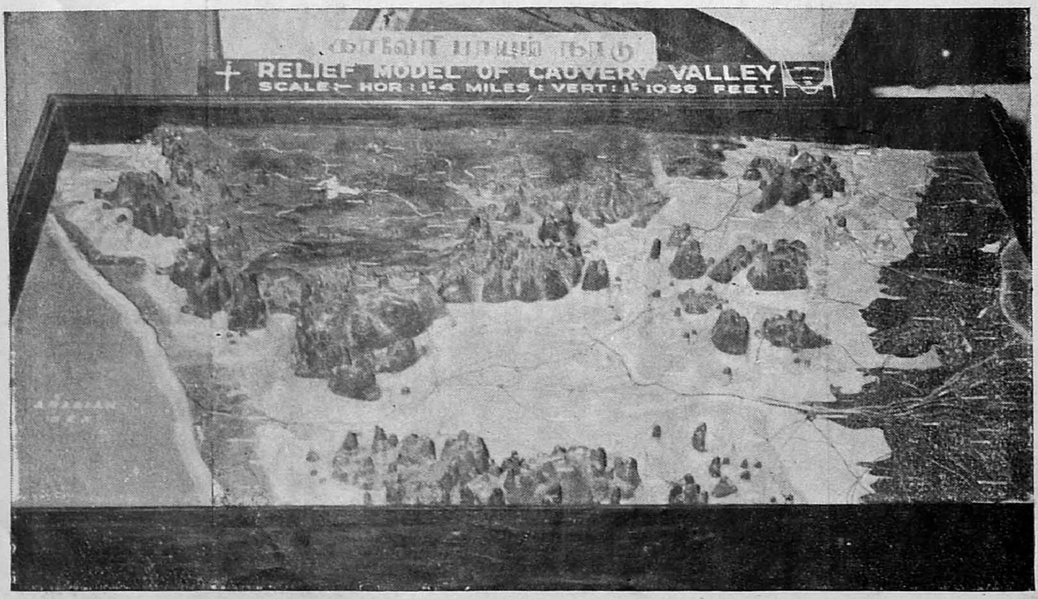
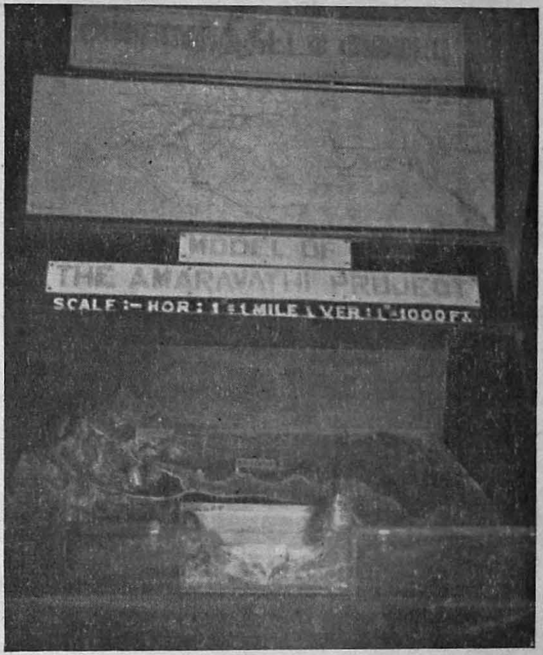


Figure 4.

6.4. The next exhibit illustrated an experimental work carried out at the Irrigation Research Station, Poondi to evolve a method of flushing, with sea water, the Cooum River which remains stagnant for a major part of the year on account of a sand bar across its mouth thereby creating an unhealthy atmosphere within the city limits. Sea water is let into the river and flushed out into the sea through pipes laid across and under the bar taking advantage of the tidal ebb and flow in the Bay.

6.5. Coloured and illuminated photographs showing the progress of the Projects under the "Five Year Plan" were displayed as the fifth exhibit. The photographs were mounted on an automatic rotating mechanism with alternate "Stop and go" movement to afford sufficient time for each set of pictures to be examined vide figure below.

6.6. Next in order, were placed the following three models. First was a dioramic representation of the Mettur Dam model with its features merging into a painting in the background to produce the effect of an apparent extension of the model on to the distant horizon. Next was an illuminated model of the Amaravathi Project area painted in brilliant flouroscent colours brought out by ultra violet illumination.



Illuminated Model of Amaravathi Project Area

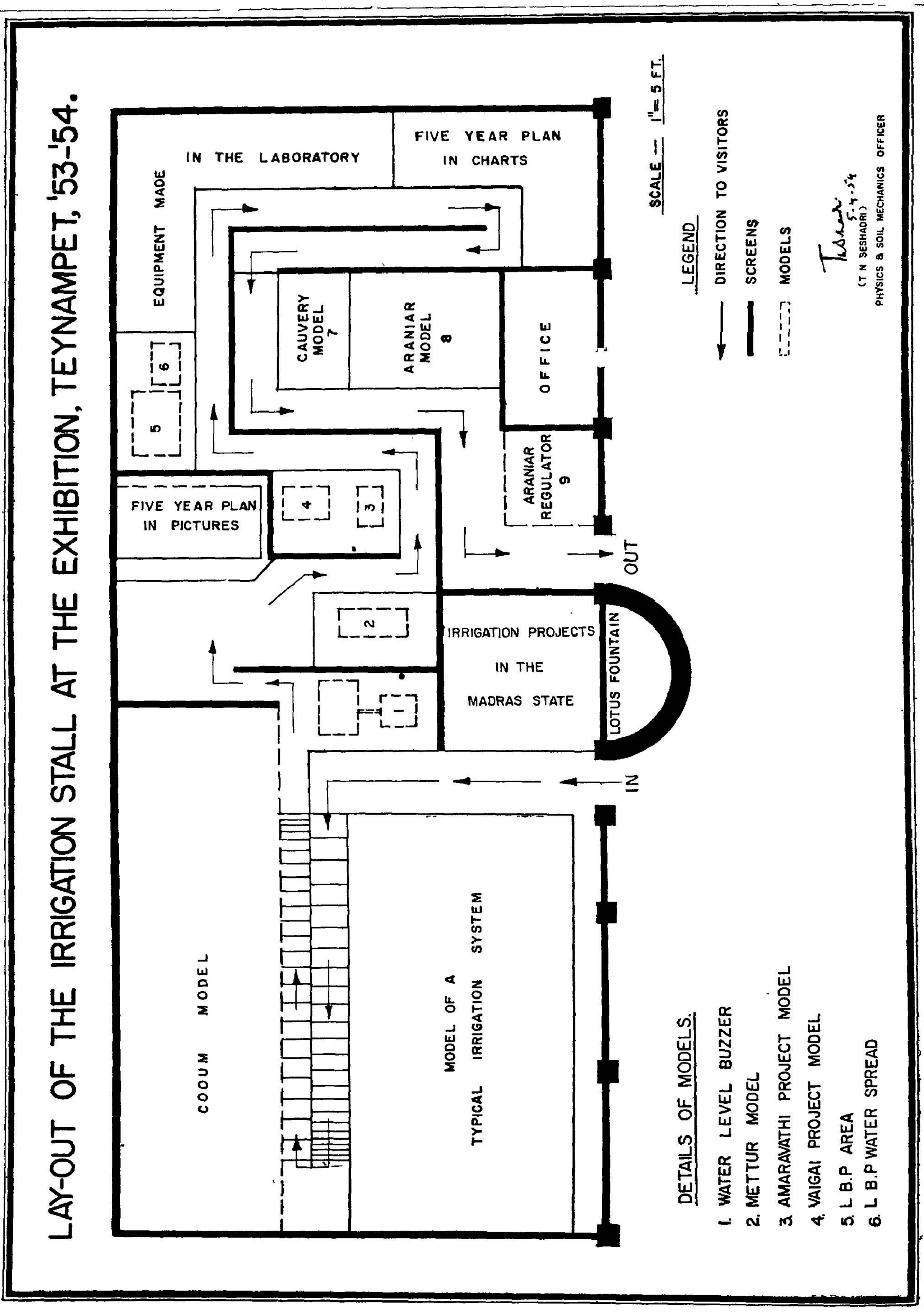
A lighted model of the Vaigai Reservoir Project area came last.

6.7 The Lower Bhavani Project headworks, with the dam, Reservoir and the canal taking off from it was shown in the next model. The area served by the Project was included and shown separately coloured. The actual flow of water in the rivers and canal was also simulated realistically in the model. (Figure 3 of Art Supplement).

6.8. A few of the equipments designed and manufactured in the Concrete and soil Engineering Research Station at Chepauk, for use in the testing of Soils, Concrete and other materials were exhibited next, mainly with a view to indicate the specialised type of work carried out in the Workshop attached to the Research Station.

6.9. The salient features and other details of the Five Year Plan Projects in the Madras State were shown next in a series of educative charts.

6.10. A model of the Cauvery Valley, carved out in wood showing the entire extent of the Cauvery Basin with its three important reservoirs, the Krishnarajasagar, the Mettur Reservoir and the Bhavanisagar, was another


LAY-OUT OF THE IRRIGATION STALL AT THE EXHIBITION, TEYNAMPET, '53-'54.
EQUIPMENT MADE
IN THE LABORATORY
FIVE YEAR PLAN
IN CHARTS
CAUVERY MODEL 7
ARANIAR MODEL 8
OFFICE
ARANIAR REGULATOR 9
FIVE YEAR PLAN
IN PICTURES
IRRIGATION PROJECTS
IN THE
MADRAS STATE
LOTUS FOUNTAIN
OUT
IN
COOUM MODEL
MODEL OF A
TYPICAL IRRIGATION SYSTEM
SCALE — 1" = 5 FT.
LEGEND
DIRECTION TO VISITORS
SCREENS
MODELS
(T N SESHADRI)
PHYSICS & SOIL MECHANICS OFFICER
DETAILS OF MODELS.
1. WATER LEVEL BUZZER
2. METTUR MODEL
3. AMARAVATHI PROJECT MODEL
4. VAIGAI PROJECT MODEL
5. L B.P AREA
6. L B.P WATER SPREAD

interesting exhibit (A photograph of this model is given in Figure 4 Art Supplement).

6.11. The next exhibit was an illuminated model of the Araniar Project area, with the contours built up in layers of wood. A Preliminary design of the Araniar Dam and Regulator was also exhibited.

7. The choice of these exhibits and their display as already stated, was with a view to bring before the public, the main features of Irrigation Projects of the Madras State included in the Five Year Plan and the benefits that would accrue therefrom.

8.1.1. The Hon'ble Sri K. Venkataswami Naidu, Minister for Religious Endowments after visiting the stalls remarked " This stall is very good, very educative and well arranged. It has good publicity value also ".

8.1.2. Distinguished public men have congratulated the Public Works Department "for the excellent exhibits of an educative value showing the construction and the working of the Irrigation Projects already executed and under contemplation in the Madras State ".

8.1.3. The need for a permanent exhibition of this kind in a central place in the City and also the need to make arrangement for displaying the exhibits and models from village to village were also stressed by a number of prominent persons including the President of the Tamil Nad Congress Committee, who visited the stall and recorded their impressions in the Visitors' Book.

9. It will be appropriate in concluding this article, to thank the general Exhibition authorities for their kind help and co-operation, which contributed in no small measure, to the success of the Public Works Irrigation Exhibition Stall.

ANNEXURE

List of Exhibits put up at the Irrigation Exhibition Stall—Teynampet 1953–54.

1. Irrigation Projects of Madras State
2. Water level Buzzer
3. Model of a typical Irrigation System
4. Cooum Model
5. Five Year Plan in pictures (rotating photographs)
6. Mettur Model (Diorama)
7. Amaravathi Project area
8. Vaigai Project Area
9. Lower Bhavani Project Area
10. Lower Bhavani Project Waterspread
11. Equipment made in the Soil Engineering Research Station Workshops:—

Consisting of a

Microfilm Reader
Shrinkage apparatus
Liquid Limit Apparatus
Proctors Mould
U.C.S. Apparatus
Gold beck cell
Flow Table
Permeability Apparatus
Shear Apparatus
Field Testing Kit
Vibrator
Tile testing machine etc.
Five Year Plan in charts (Lower Bhavani, Malampuzha, Manimuthar, Mettur Canals, Mangalam and Walayar Cauvery Drainage Schemes and Araniar)
Model of Cauvery Valley
Model of Araniar Project Area
Model of Araniar Project Regulator

Effect of Application of an Electric Potential on the Behaviour of Soils

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Abstract :— This paper discusses in brief, the theory and the practical applications of electro-osmosis. Electro-osmosis is the movement of moisture in a capillary system on account of the application of a D.C. potential. By the application of such a potential, soil moisture can be moved effectively from the anode to the cathode in fine grained soils; and compressible fine grained soils can be consolidated.

Introduction:—In recent years the physico-chemical study of soils has attracted the attention of several workers in the field of Soil Mechanics. On account of the wide application that it has, apart from the theoretical interest, the behaviour of Soil Moisture under an externally applied electric or thermal field was taken up for detailed investigation in several soil laboratories in Europe and United States of America. The published work is not yet sufficient to formulate results having a general validity. This fact is therefore, very encouraging to the workers in India to conduct basic research on this subject and to investigate ways and means of utilising the results for the betterment of engineering practice in this country.

History:—Nearly 150 years ago it was discovered by Reuss that if an electric potential is applied to a porous diaphragm, the moisture within it starts moving towards the cathode. Wiedemann, Quinkce and others did further experimental investigation of this phenomena whereas Helmholtz, Gouy and Debye and a few others contributed a mathematical basis for this behaviour. The mathematical picture explaining this movement of moisture towards the cathode as explained by Helmholtz is accepted even to-day with slight modification.

Electro-Osmosis:—The movement of moisture in a capillary system towards the cathode on the application of an external e.m.f. is known as the phenomenon of electro-osmosis. The physical and structural changes brought about by the application of an e.m.f. are the results of electrolytic and electro-kinetic phenomena, the individual contribution of each one of these depending on the properties of the soil, moisture, and the type of electrodes used. The electro-kinetic and electrolytic phenomena are influenced by several factors like the soil formation, mineralogical composition, size, shape and mechanical behaviour of soil particles. These are too fundamental to be dealt here.

Movement of water being the primary factor, it is essential also to have certain basic information on the soil water relationship. It is not within the scope of this paper to review aspects like the different conditions under which moisture exists in soil or the stressed condition of moisture within the pores. But it will suffice to mention that in early days, soil was considered to be constituted of a large number of capillary tubes of different diameters and that water movement was due to surface tension. More recent concepts employ energy relationship.

Movement of Moisture in Soils:—Energy is required to move a film of moisture from one energy level to another energy level, and it is dependent on the difference of two energy levels (potential) and also the resistance to the flow. It is generally possible to estimate experimentally the magnitude of the potential required for causing such a flow. But little is known regarding the resistance to flow.

The usual energies causing movement of moisture are

Gravitational energy
Energy due to heat of hydration
Energy due to osmosis
Capillary forces
Energy due to vapour pressure
Thermo osmotic potential and
Electro osmotic potential

The rate and speed of movement of moisture depends on one or more of the above mentioned potentials. The scope of this paper is to give a general picture of the last of the above list and to illustrate in brief its practical applications.

An e.m.f. primarily causes a transport of pore water in the soil resulting in the reduction of water content of soil. It may also cause hardening of the soil as a consequence of electro-chemical changes such as the precipitation of aluminum hydroxide (when aluminum electrodes are used) and a final flocculation of colloidal clay substance. The transport or movement of soil water in the pores is known as electro-osmosis and is due to electro-kinetic phenomenon. This movement is due to the fact that there is an electrical charge on the soil particle due to the adsorption of ions from the soil moisture. As the positive ions have a greater energy of hydration than the negative ions the colloidal soil particles are loaded with negative charges. The water having thus the positive charge, moves towards the cathode. In soils containing electrolytes the effect of electrokinetic action is found to be comparatively lesser.

As we consider the soil to be a bundle of capillaries, it is but right that we should understand the flow of moisture in a single capillary. Helmholtz proposed that between the wall of the capillary and the free water within, there is a film of water known as " Double Layer " so named on account of the assumption of the existence of opposite charges on two layers of the film as shown in figure 1. The layer closer to the capillary, which is relatively thinner than the remaining part of the double layer, carries a negative charge and is attached to the wall of the capillary. The thicker part carrying the positive charge is the movable part of the double layer. This was termed as movable by Helmholtz as the application of an e.m.f. causes movement of the positive charge towards the negative pole. The free cylinder of water inside the capillary tube is dragged along by the movable part as it is completely enclosed by it. (In certain exceptional cases moisture is found to move towards the anode.)

In the absence of other forces acting on the free cylinder of water, the rate of flow is constant and the velocity distribution within the capillary is as shown in figure 1 in contrast to the free hydraulic flow, in which the velocity is zero along the inner face of the double layer or the surface of the capillary wall, in view of the infinitesimally small thickness of the double layer.

Strictly speaking this is not the correct picture of the velocity distribution in the hydraulic flow system. On account of the relative movement of water with respect to the solid phase an e.m.f. is set up in the double layer (streaming potential) and the velocity distribution is modified.

Terzaghi, Nutting and other workers in this field have determined the thickness of the double layer to be of the order of 10 to 1000 $\mu\mu$ where $\mu\mu$ represents one millionth m.m or one thousandth micron. It has also been concluded that the thickness of the double layer depends on the concentration of the electrolyte in the liquid phase.

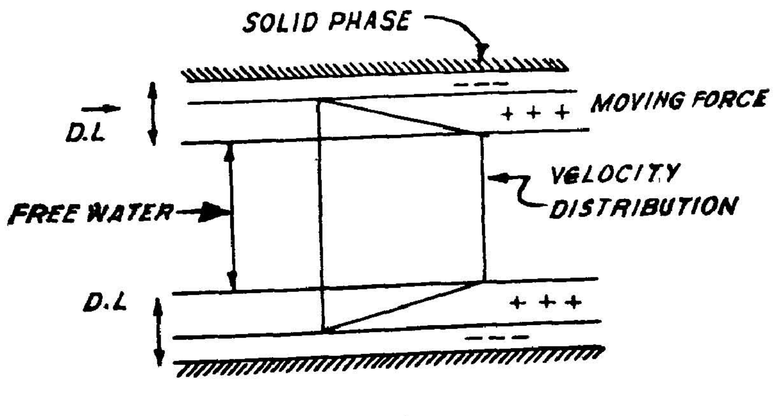

FIG. 1.

Theory of Electro-osmosis: According to the modified equation of Helmholtz, the quantity of liquid moved in unit time through a single capillary under a potential difference 'E' is given by

$$Qe = \frac{E\,D\,R^2\,\vartheta}{4\,n\,l} \text{ where}$$

D = dielectric constant of the liquid
R = radius of the capillary
ϑ = electro-kinetic potential or the potential existing between the rigid and the movable parts of the double layer.
n = viscosity of the liquid
l = length of the capillary

Instead of one capillary, if we take into consideration a prism of soil saturated with the liquid with an area of cross section 'A' in contact with the electrodes and of length of 'l' then the total quantity of liquid passing is given by

$$Qe = \frac{E\,D\,R^2\,\vartheta}{4\,n\,l} . A$$

$$= \frac{E\,D.\,\vartheta}{4\,n\,l} . q . A$$

Where q is a function of the void ratio and the cross section of the pore space thro' which the liquid is moving.

$$= \frac{D\,q\,.\,\vartheta}{4\,n} . \frac{E}{l} \times A$$

$= Ke \,.\, i_e \,.\, A$—(1) where i_e is the electric potential gradient in analogy with the hydraulic flow and

$$k_e = \frac{D\,q\,.\,\vartheta}{4\,n}$$

which is a constant for a given soil specimen. This term is known as the electro-osmotic permeability and has been defined by Prof. Winterkorn as the volume of water passing through a cross sectional area of 1 sq. cm. per volt/cm per second.

Equation (1) is very much similar to Darcy's law for hydraulic flow which can be stated as

$Qh = k \,.\, i_h \,.\, A$ where A is the cross sectional area of the prism, i_h is the hydr. gradient and k is the permeability of the soil.

Inspite of this superficial similarity of the two equations, it should be noted that there is a fundamental difference between k and k_e; while k_e is dependent mainly on the pore area and is independent of the size of the individual pores, k is dependent on the actual size of pores. From this it can be concluded that k_e remains the same for sand, silt or clay provided that "ϑ" remains constant for these materials. It has been observed that "ϑ" does not vary very much within the usual range of concentration of electrolytes as found in soils. These facts have been confirmed experimentally by Dr. L. Casagrande who conducted tests on London clay, rock flour, clayey silt etc.

How these principles of electro-osmosis can be adopted for draining water in foundation engineering is clearly explained by Dr. L. Casagrande as follows :—

> "If the magnitude of $k_e = 0.5 \times 10^{-4}$ cm/sec for one volt/cm is compared with hydraulic permeabilities of fine grained soils, the answer becomes immediately clear. There are excellent possibilities of moving pore water in silts and clays by this method; but no advantageous results can be expected if electro-osmosis is applied to coarser materials- *e. g.* the application of electro-osmosis to a fine sand with hydraulic co-efficient of permeability $k_h = 50 \times 10^{-4}$ cm/sec will not be advantageous. A discharge velocity of one volt/cm, will of course, not interfere with a velocity of 50×10^{-4} cm/sec that would result from an existing hydraulic gradient of unity. This picture changes quite radically if electro-osmosis is applied to a clay which has a hydraulic co-efficient of permeability of the order of 10×10^{-9} cm/sec. To compute for this clay the hydraulic gradient which would cause the same rate of flow as a potential gradient of i_e one volt/cm, we equate $i_h \,.\, k_h = i_e \,.\, k_e$
>
> whence
>
> $$I_h = i_e \,.\, k_e / k_h$$
> $$= i_e \,.\, \frac{0.5 \times 10^{-4}}{10 \times 10^{-9}}$$
> $$= i_e \,.\, 5000$$
>
> *i.e.*, a head of about a mile for a distance of about one foot."

From the example shown above, it can be very easily appreciated how the principles of electro-osmosis can be advantageously made use of in draining soil moisture from a fine grained soil whose hydraulic co-efficient of permeability is low.

***Hydraulic pressure at the cathode*:** If pore water which is transported towards the cathode on the application of an external e.m.f. is allowed to head up in a standpipe, the hydrau-

lic pressure goes on increasing at the cathode and ultimately a stage will be reached when the electro-osmotic pressure will be balanced by the hydraulic pressure. It has been established that the maximum hydraulic pressure at the cathode is given by

$$p = \frac{2 \zeta E D}{\pi R^2}$$

This could also be expressed in a more simple form as

$$P = \frac{Ke}{K} \times E$$

Laboratory Work—Equipment : The usual apparatus adopted for investigations on parallel flow is as shown in figure 2. The electrodes

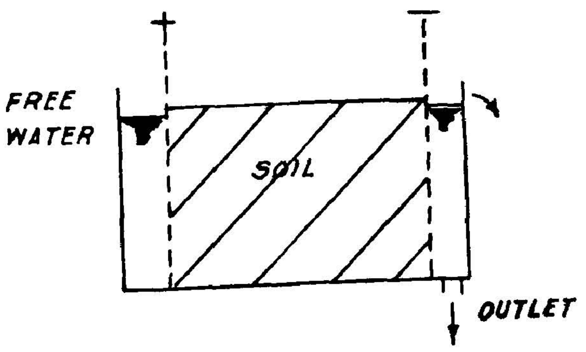

FIG. 2.

are in the form of plates or wire gauze depending on whether the moisture should flow through the electrodes or not. The soil is thoroughly mixed with water so that the water is uniformly distributed throughout the sample. Generally the amount of water used corresponds to the liquid limit of the particular soil. D. C. voltages upto 200 volts are necessary and potential gradidents from 0.1 to 12 volts centimeter are obtained either by changing the distances between the electrodes or by resistances connected to the supply line. The external applied potential is kept constant as far as possible during the test. The D. C. system should be capable of giving high amperages. As the cessation of current supply on account of any breakdown for a long time is likely to cause very undesirable effects, a spare D. C. unit must be had ready for immediate feed.

The electrodes used in the laboratory investigations are generally made of platinum or iron anodes and platinum or copper cathodes. It should be noted that iron anodes are subjected to corrosion.

On the field, it is usual to make use of the sheet piling of an excavation as the anode. Otherwise old iron pipes of 1" to 2" diameter are driven into this soil to serve as anodes. The anodes being subjected to corrosive effects as electro-osmosis proceeds, it is desirable to replace the anodes as soon as the current consumption drops to less than a third of the initial consumption. The cathodes are generally made of copper gauze and they are arranged in the form of wells so that the water which is attracted to these well points can be easily pumped out. Wells can be had by having a system of separate cathodes or by a single cathode itself (Refer figures 3 a and 3 b.).

Except in exceptional cases the general rule is that both cathodes as well as the anodes are driven to the same depth.

As the potential gradient between the electrodes is most important in the electro-osmotic function, the distance between the electrodes has to be suitably fixed, taking into consideration the field conditions. The electrodes can be placed in a row of alternate anodes and cathodes or the anodes can be placed single or in groups, depending largely on circumstances.

As voltages of the order of 100 to 220 are made use of, care must be taken to see that there is no short circuiting either by earth moving machinery or otherwise. The workers in the region must be advised to take the usual precautions.

Results : From a large number of tests conducted in the laboratory the following important results have been obtained :

1. Discharge of water is proportional to the potential gradient.

2. Water distribution at different distances from the electrodes and at various intervals of time after the commencement of the experiment depends on the external conditions such as (i) the presence of water above the water surface (ii) free water available outside the anode (iii) no access of water from outside.

3. When high currents are applied, the region round the anode gets heated up. The

temperature gradients thus produced increase the transport of water caused by electro-osmosis alone.

4. With free water available at the electrodes laboratory tests on clay samples have yielded some important results. The following are a few of these important inferences:

1. Electro-osmosis induces a tensile stress in the pore water and a compressive stress resulting in a corresponding amount of consolidation on the grains of the soil skeleton.
2. Rate of discharge of water at the cathode continues for many weeks at an almost constant rate and finally drops off gradually with a corresponding decrease in the electric current (to about $\frac{1}{4}$th of the original current).
3. "Rhythmic" repetition of fissures parallel to the face of the cathode occur leading to shrinkage of clay at one electrode and swelling at the other electrode.

***Practical Applications*:** From the foregoing paragraphs it can be immediately concluded that the electro-osmotic phenomena can be readily made use of in stabilisation of soil strata at large depths for which other methods of soil stabilisation cannot be applied. Apart from being able to drain the sub-soil water and thus increase the bearing capacity of the soil, this process indirectly consolidates the soil layers. Dr. Leo Casagrande has adopted electro-osmotic method in stabilising unstable slopes in Germany and this technique has also been used in improving the structural behaviour of soils in railway embankments and tunnel works. Excavations in highly marshy regions and water logged areas has been made possible by draining the pore water by the application of an external electric potential between suitably placed electrodes. Dr. Leo Casagrande quotes several examples where these methods were successfully tried in various parts of the continent. The draining and strengthening of a railway embankment of the Scottish Railway, electro-osmotic stabilisation of a railway cutting in Salzgitter in Germany, subsoil drainage for deep excavation in the construction of a u—boat pen in Norway are some of the few successful applications where electro-osmosis has been adopted to achieve.

(i) excavation efficiency
(ii) draining of sub-soil moisture; and

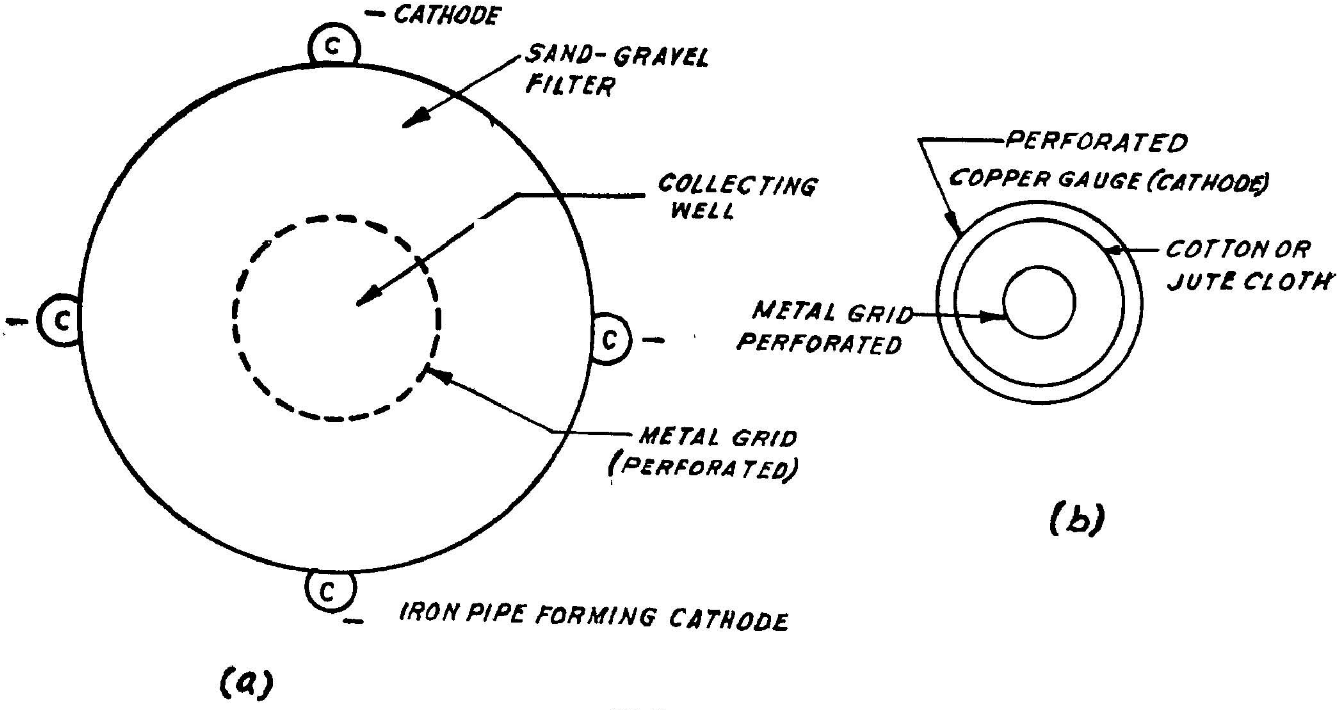

FIG. 3.

(iii) reduction in settlement of the super-structure by pre-consolidation.

Further, it is possible to combine the technique of electro-osmosis and electro-chemical deposition in soil-stabilisation by a proper choice of electrodes. By using aluminum anodes aluminum hydroxide precipitates and 'solidifies' the soil. Compressibility is decreased considerably and the internal frictional resistance of the soil is increased. It is needless to state that these are the two important factors influencing the structural behaviour of the soil. With the increase in internal frictional resistance and reduction in compressibility, the soil is rendered more useful to the engineer.

Conclusions and prospects : The theoretical background for the electro-kinetic and electrolytic processes is purely related to the field of physics and physical-chemistry. It is therefore very desirable that pure scientists offer their aid and assistance to the engineer to evolve a more rational and more systematised technique of exploiting the soils to the fullest.

The practical applications of electro-osmosis are tempting enough to be tried in our country. Soil stabilisation methods are not very widely adopted in India in any of our projects and there seems to be no dearth for field problems for applying these techniques. Either in the field of foundation engineering, irrigation engineering practice or in railway or highway construction, soil stabilisation plays an important roll and it is needless to state what an important tool electro-osmosis is in the field of soil stabilisation. The technique being still new the economic side of the problem is yet a questionable aspect. But it is very necessary to adopt these new methods with a spirit of adventure.

Acknowledgement

I am deeply indebted to Prof. N.S. Govinda Rao who suggested this topic to me for theoretical and experimental study and who gave valuable advice while reviewing the manuscript.

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TANK WEIRS

A Change from Traditional Design for Efficiency and Economy

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1. Introduction :

1.1 Tank Weirs are essential adjuncts for the formation of tanks as they ensure safety of tank bunds by letting out surplus flood flows beyond the capacity of the tank. In this respect they may be likened to the safety valves in boilers which open out automatically and let out steam beyond the limiting pressure and thus save the boilers.

1.2 The design of these weirs calls forth ample fore-thought and a correct appreciation of the potentiality of the high flood flows. Whilst overcaution may result in uneconomical constructions, curtailments in provision, on the other hand, may throw open the tank bund to recurring hazards and even an ultimate collapse.

1.3 Long tank weirs formed with broad crests had been in vogue, in the past, when the availability of labour and materials was so abundant as not to cause any restriction in imposing massive barriers, where short and sharp obstructions would have done its duty equally well.

1.4 With the changing times and increased cost of labour and materials, the need to economise on cost without infringing on the utility of these structures has called for a change from the traditional types of construction.

1.5 An example of this is a High Co-efficient Weir which is a product of modern engineering technique aiming at reduction of long lengths of weirs by creating conditions of greater discharge which would result in economy in overall costs. Alternatively, the lesser overflow depths over the weir would reduce the area of submersion, under the water spread of the tank.

1.6 The improvements to tanks are in a great measure handled by the Food Production Department which aims mainly at the restoration of old tanks taken over from abolished estates and Zamindaries. In its functioning, the Department has to take up for execution a wide variety of works and several existing structures are made use of, as far as possible, after repairing them. New masonries are resorted to only if they are found to be absolutely necessary. In such reconstructions it is therefore usual to come in contact with different types of weirs.

1.7.1 An example of an existing weir constructed in the past and therefore amply proportioned is in existence at Panaiyur village in the Sankaran Koil Taluk, Tirunelveli District. Here large blocks of granite pillars, being the remnants of some dilapidated mandapam, have been stacked in a wide array and a barrier has been built across a gap in the tank bund to function as a surplus weir. Capitols over the columns with their ornamental freizes have also been built in, and give a pleasing effect to the mighty edifice.

1.7.2.1 This is an example of a weir which has been constructed more for utilisation of available materials than for design requisites and its construction may be justified as being the most utilitarian type under the circumstances then obtaining.

1.7.2.2 Construction of weirs nowadays cannot obviously be on such liberal lines and the modern engineer has to construct weirs at minimum cost and maximum efficiency. An example of a weir of this type is the High Co-efficient Weir at Melaiyur village in the Ramanathapuram District. The details of the tank and weir are furnished below as this represents *a change from traditional type for efficiency and economy.*

2. Location and Particulars of the Tank :

2.1 Melaiyur tank is situated six miles north of Paramakudi Town and three miles west of Ilayangudi village. An index map (Figure 1.) gives details of location and the catchment of the tank which has a registered ayacut of nearly 1,230 acres out of which only 1,000 acres have been cultivated for the past six or seven years. In order to restore the gap of 230 acres and

INDEX MAP SHOWING CATCHMENT AREA OF MELAIYUR TANK

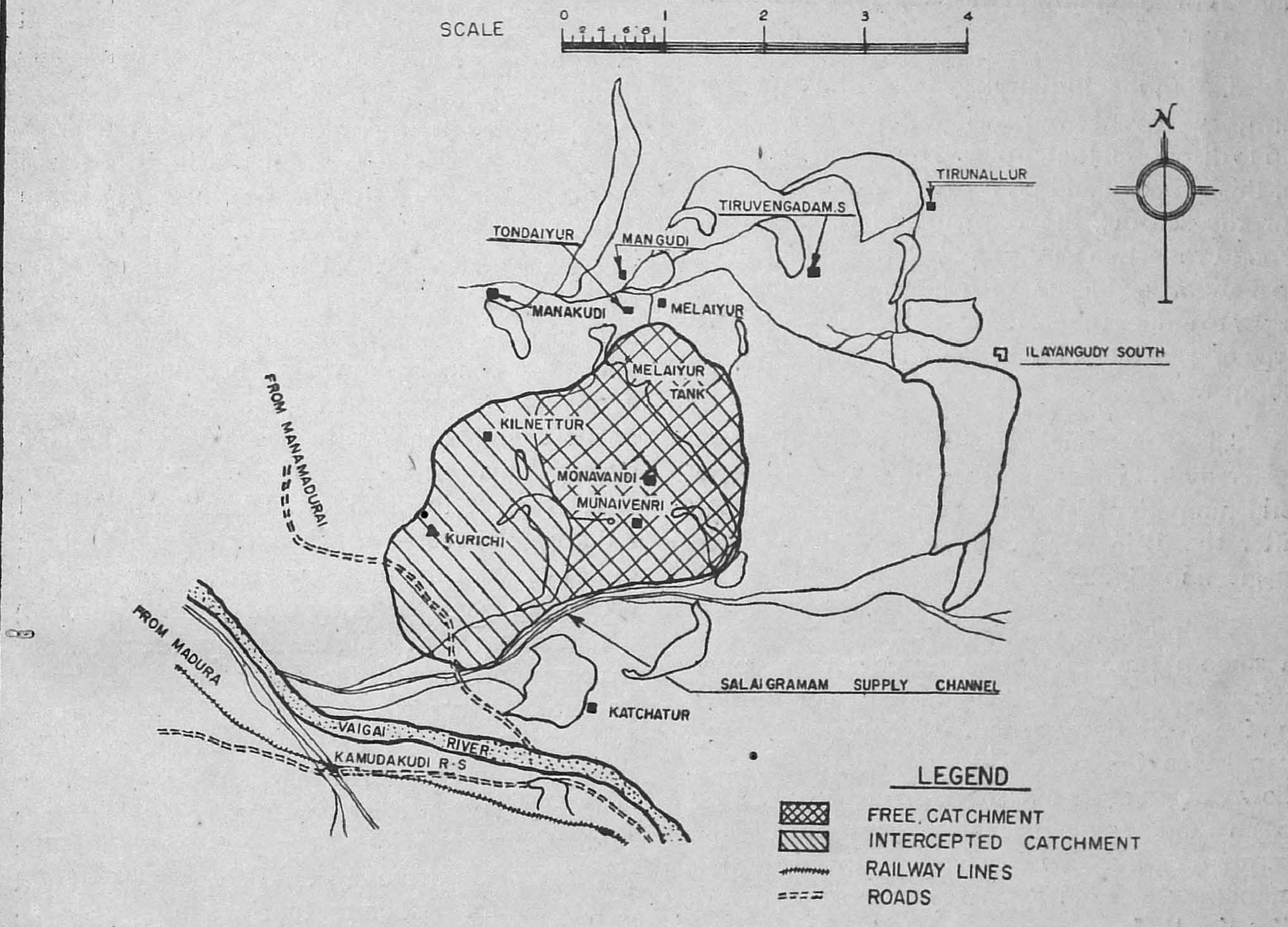


FIG · I

increase the Food value of the ayacut under it this tank was taken up for reconditioning by the Food Production Department.

2.2 The tank has a free catchment of Four square miles and a combined catchment of Seven square miles. An average yield of 36 Million Cubic Feet (M.Cft.) can be depended upon from the catchment. This yield is likely to be further augmented by flow from a supply channel taking off from river Vaigai through an open head which may bring in 213 M.Cft. at an average of two and a half fillings per annum. Thus a total flow of 36 + 223 = 259 M.Cft. may be reckoned for design purposes. This can supply the needs of nearly 1,300 acres. As the registered ayacut is only 1,230 acres, there will be some margin for future extensions also, if found necessary.

2.3 The tank has a waterspread of about 1.3 square miles and a depth of 8.2 feet in the deepest portion. With two and a half fillings per annum, 246 M.Cft. of water can be impounded which will enable the cultivation of a registered ayacut of 1,230 acres at the rate of five acres per M.Cft., after the present stage of improvements is completed.

2.4 The tank had no regular surplus weir and the ryots used to cut open the bund and create a breaching section, during emergencies of flood. This was not a desirable method of disposal of surplus and hence regular surplussing arrangements had to be provided for, during reconstruction.

3. Surplus Weir :

3.1 The total surplus discharge to be provided for under M.F L. conditions will be in the

order of about 1,590 cusecs. This will comprise of (i) the maximum flood flow in the catchment taking a value of 450 for C in the Ryves' formula and (ii) the flood flow in the supply channel from the River Vaigai.

3.2 In the initial stages of estimating, an ordinary type of weir was proposed to be built up to dispose off the surplus. During the scrutiny of this proposal and prior to according approval for the scheme, the Superintending Engineer, Food Production Circle suggested a change over to a High Co-efficient Weir if found suitable, in order to reduce the cost. Accordingly the revised type of weir was adopted, as it worked out to be cheaper.

3.3 The High Co-efficient Weir was generally designed on the lines of the new Sriperampudur tank weir which was constructed after the 1943 floods. A sketch of the weir is given in Fig. 2.*

The profile of the weir is such as to induce a smooth transition of hyper critical flow over the weir, enabling a standing wave to be formed on the glacis downstream. A baffle is thrown parallel to the weir and six and a half feet downstream of its toe so as to create a stilling basin and complete the dissipation of the surplus energy. To give an upward deflection of high velocity jets, energy dissipating blocks 1' x 1' x 1' 6" in two rows at 2' 0" centres are provided. A talus to the rear of the solid apron completes the protection against scours.

3.3.1. The design also incorporated the following features.

(1) Provision of a masonry cut off wall 3' 0" deep at the front edge of the foundation concrete for the body wall; and

(2) Introduction of a clay blanket of two feet depth and ten feet length in front of the weir as shown in Figure 2.

The clay blanket cum cut off wall is an improvement on the provision of a routine front apron protection and is more effective in reducing percolation and flattening out the exit gradient.

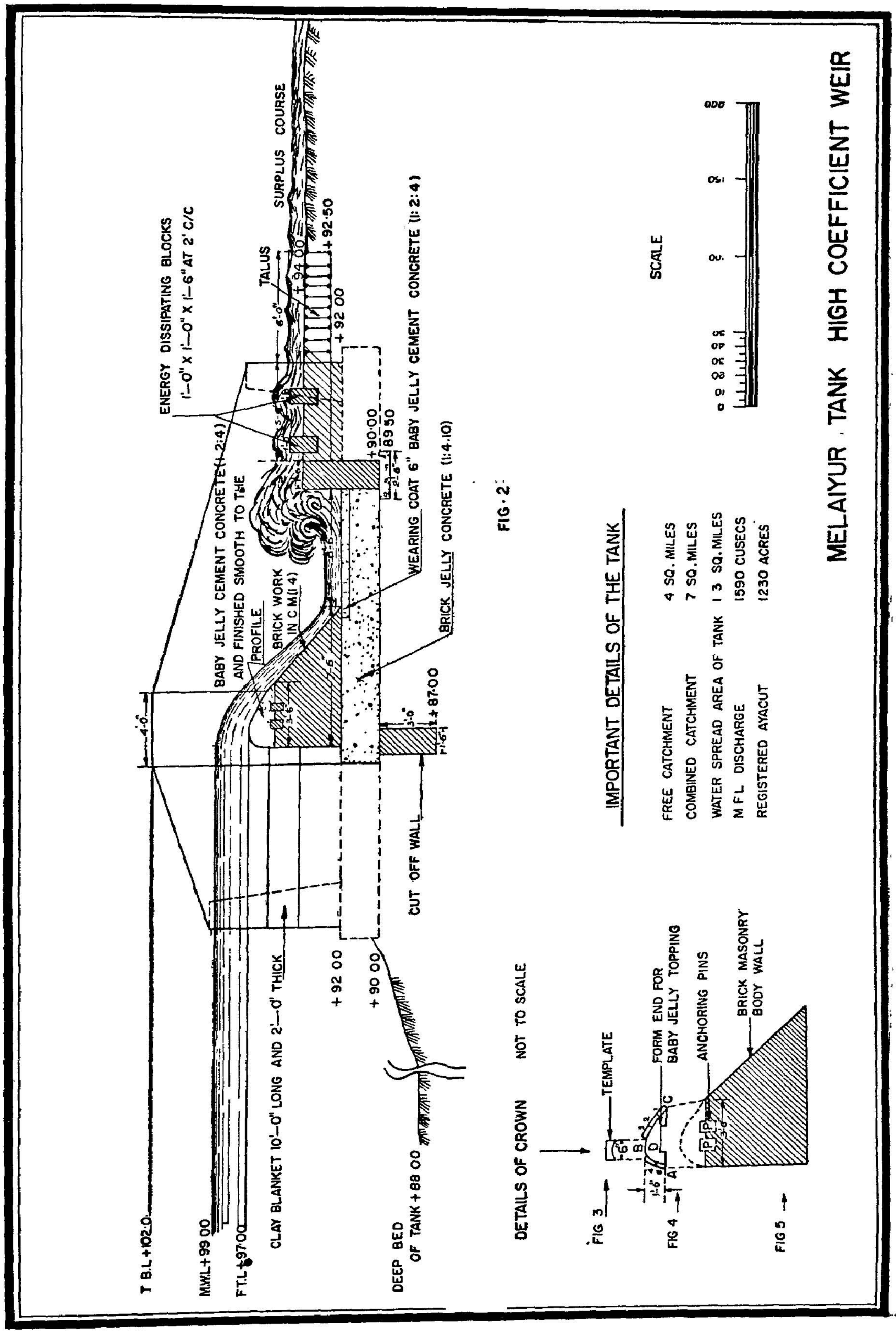
4 Details of Construction.

4.1. No serious difficulties were encountered during the construction. The only snag was in the formation of the concrete capping of the weir to the proper curvature and even this was successfully tackled after some deliberation.

4.2. For this purpose, the actual cross section of the body wall including the crest portions was drawn to full size on a platform laid out at the site of works. A number of wooden templates A, B, C, D (vide Figure 4*) to suit the curvature were made. Keeping two such pieces at four feet intervals five battens were nailed on them as shown in the figure leaving a gap of six inches at the crown B. Six pairs of these templates were assembled end on end, over the flat portion of the body wall for a total length of about 25 feet. These templates had a rectangular recess at D which enabled them to key in with the masonry anchoring pins P P projecting from the body wall (vide Figure 5*.). The anchors were built in side by side with the bottom portions of the body wall and were meant to serve the purpose of binding up the top sections, with the whole structure. The recessing at D fitting well as it did as a sleeve with P P gave perfect rigidity to the template and prevented its lateral movement. The absence of this groove would have necessitated going in for elaborate bracings to keep the shuttering in tact.

4.3. After fixing the six form works, well graded baby jelly concrete was introduced through the gap at the crown, in layers of six inches and consolidation was effected by poking the interior space thoroughly. The battens were also gently tapped so as to give the necessary vibration effect. The top gap was finally closed up using another template (vide Figure 3*) to get at the proper curvature at the crest. Allowing a period of 48 hours for setting, the form boxes were removed enbloc and reassembled for the next 25 feet length of weir. Annular gaps of two inches at the location of the templates were subsequently grouted in with rich concrete and finished with proper care. The newly formed crest was given a thorough curing and the full body wall from heel to crest and crest to toe was plastered over to give a smooth and good finish.

*Facing page.


ENERGY DISSIPATING BLOCKS 1'-0" X 1'-0" X 1'-6" AT 2' C/C
SURPLUS COURSE
TALUS
+94.00
+92.50
+92.00
+90.00
89.50
BABY JELLY CEMENT CONCRETE (1:2:4) AND FINISHED SMOOTH TO THE PROFILE
BRICK WORK IN C M (1:4)
WEARING COAT 6" BABY JELLY CEMENT CONCRETE (1:2:4)
BRICK JELLY CONCRETE (1:4:10)
+87.00
4'-0"
CUT OFF WALL
CLAY BLANKET 10'-0" LONG AND 2'-0" THICK
+92.00
+90.00
T.B.L +102.0
M.W.L +99.00
F.T.L +97.00
DEEP BED OF TANK +88.00
FIG. 2
IMPORTANT DETAILS OF THE TANK
FREE CATCHMENT 4 SQ. MILES
COMBINED CATCHMENT 7 SQ. MILES
WATER SPREAD AREA OF TANK 1.3 SQ. MILES
M F L DISCHARGE 1590 CUSECS
REGISTERED AYACUT 1230 ACRES
SCALE
DETAILS OF CROWN
NOT TO SCALE
TEMPLATE
FORM END FOR BABY JELLY TOPPING
ANCHORING PINS
BRICK MASONRY BODY WALL
FIG 3
FIG 4
FIG 5
MELAIYUR TANK HIGH COEFFICIENT WEIR

5. Advantages of this Type of the Weir

5.1. The co-efficient of discharge for a broad crested weir in the formula $Q = CLH^{3}/^{2}$ will be of the order of Three (C = 3); with a high co-efficient profile the C value may be enhanced upto four and a half (C = 4.5). A Curtailment of length will therefore be possible for disposing off the same discharge under the same head by adopting a High Co-efficient profile in preference to a routine profile. This will result in a certain amount of economy in construction costs. The cost. of protective works in the case of a High Co-efficient Weir will, however, be more than in the routine type, on account of the release of extra energy of the falling water due to constriction in length, and the necessity to go in for elaborate energy dissipating arrangements. Hence the adoption of the High Co-efficient profile has to be decided upon, in each case, after a relative study of the alternatives.

In the present case, the High Co-efficient profile weir was cheaper than the ordinary crested weir by Rs. 2,160 in an estimate of of Rs. 14,417.

The following comparative table, furnishes the relative costs between the regular and High Co-efficient Weir alternatives for this tank.

COMPARATIVE STATEMENT OF COST

S. No.	Description of work	Narrow Crested Weir (A)			High Co-efficient Weir (B)		
		Quantity in units	Rate per unit	Amount	Quantity in units	Rate per unit	Amount
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Rs. As.	Rs. As.		Rs. As.	Rs. As.
1	Earthwork for foundation	53	17 0	901 0	40	17 0	680 0
2	Refilling with excavated earth etc.	53	9 0	477 0	40	9 0	360 0
3	Concrete broken brick jelly in C. M. 1:4:10	36	78 6	2,822 0	47	78 6	3,684 0
4	Brick work with country brick in C. M. 1:4	87	110 12	9,636 0	44	110 12	4,873 0
5	Plastering with C. M. 1:3–½″ thick	50	11 10	581 0	33	11 10	384 0
6	Baby jelly concrete in C. M. 1:2:4	...	...	...	7.40	215 0	1,592 0
7	Rough stone dry packing for apron	...	...	...	10	68 6	684 0
	Total			14,417 0			12,257 0

Difference in cost between A and B = Rs. 14,417—Rs. 12,257 = Rs. 2,160

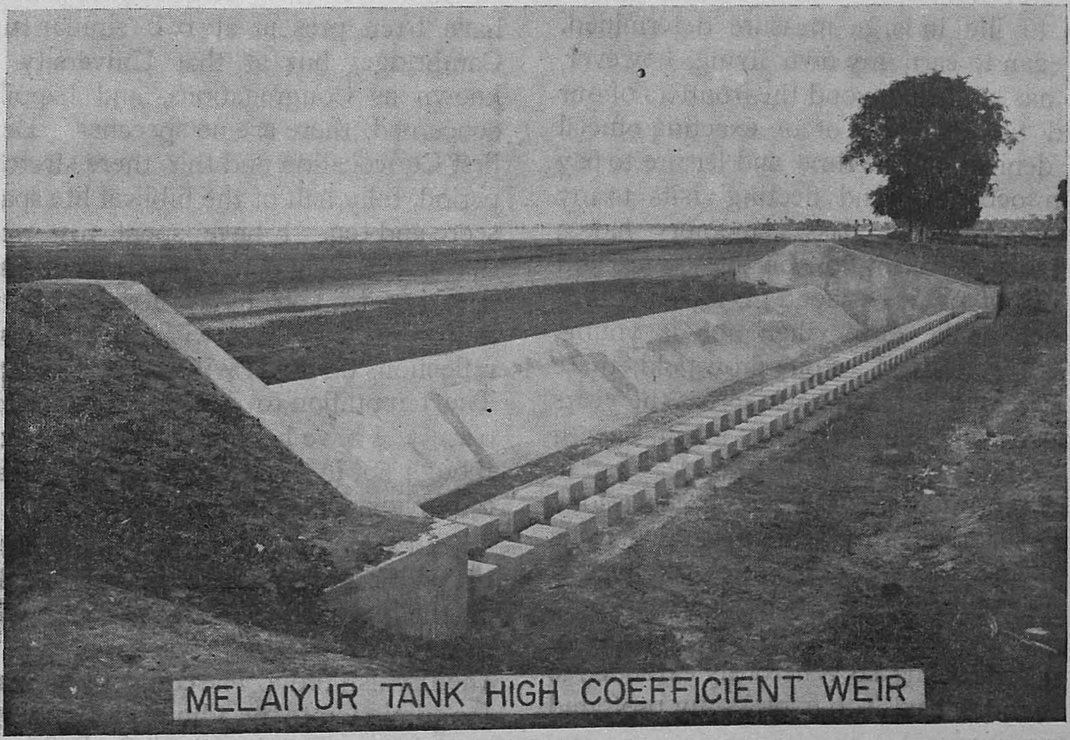
5.2.2. Due to competitive quotations for the work and the insistence of the interested ayacutdar who was also the lowest tenderer to take up the work, the cost got reduced by another Rs. 4,100. This is however merely mentioned in passing, as it does not come in for a relative study of the merits between an ordinary and High Co-efficient Weirs.

6. Period of Completion

6. The work was started in August 1951 and was practically completed by November 1952. There had been a number of changes in the incumbency of Executive Engineers, who were in charge of the work. Sri C. M. Gopal, Assistant Engineer, Paramakudi had however stayed on through the stages, right from start to finish and has made a good job of it. A photograph of the completed structure is appended below.

7. Conclusion

7. The tank is now set to standards and the weir is practically completed in all respects. It now remains for Nature to fill in Her bounty unreservedly into this receptacle of hard human endeavours and bring joy to the famished ryots under the tank. Having lavished Her plenty it will be a grand sight for those who are previleged to see Her, when She would glide gracefully along the smooth curves of the new construction and saunter on with speed and merriment to fullfil Her further mission in giving succour to Her needy children from one receptacle to another.



MELAIYUR TANK HIGH COEFFICIENT WEIR

Public Service

[*Introduction:* The following is a reprint from the publication of the Government of India, Planning Commission, entitled "The Public Service". This was the subject matter of an address delivered by Sri N. Raghavan Pillai, I.C S., Secretary-General, Ministry of External Affairs at the Nineteenth Convocation of the University of Travancore on December 18, 1953.]

"**Your Highness the Chancellor, Mr. Vice-Chancellor, Graduates of the year, Ladies and Gentlemen,**

To me, perhaps even more than to you, graduates of the year, this is a memorable occasion. Here, in Trivandrum, many years ago, in its classrooms, laboratories and libraries, I received my early education. I was for three years in the Maharajah's High School, and for two in the Maharajah's College. Later after graduating from the Madras Christian College, I returned here to spend a year in the Law College, before going to Cambridge. Here it was that the foundations of my education were, as I hope, well and truly laid, my intellectual interests first developed and my attitude and approach to life in large measure determined. Since I began to earn my own living, however, my work has lain far beyond the frontiers of our State, and the demands of an exacting official life have denied me the time and leisure to pay more than occasional and fleeting visits to my home town. As time passes, memory fades; but it still casts a warm glow on the scenes and associations of one's boyhood; one's emotional roots, which strike deep when one is young, seldom decay. Indeed, as one grows old, there comes a yearning to reach back across the years to the days of one's youth, to live again, even if only for a while, amid the schemes treasured in one's earliest memories. Nothing, therefore, could have gladdened my heart more than to be invited to come to Trivandrum to take part in an academic function of such significance to youth as a Convocation. To the University of Travancore which has so generously extended to me this honour, I wish to express my profound sense of gratitude.

Nor is this the only reason which for me makes this a unique occasion. It was chance that guided my hesitant steps to the profession to which I now belong. At the time of my graduation, my thoughts were centred on entering the teaching profession, and but for a series of unexpected events, teaching might well have been today my chosen vocation. Fortunately for them, owing to my change of plans, countless numbers of students have escaped a fate which, I am sure, they would not have deserved. To me, however, the opportunity afforded by this Convocation represents the fulfilment, though in an unexpected form of a wish long cherished.

As I stand before you today, my mind goes back to the day when I first attended a University Convocation. That was in 1918, when I was admitted for the first time to a University degree; then, as now, the ceremonial included an Address to the new graduates. Since then, I have been present at two similar functions at Cambridge, but at that University these are known as Congregations, and happily for all concerned, there are no speeches. Between my first Convocation and this, there stretches a long period, fully half of the biblical life span of three score and ten. I have spent my working life during this long period in the Civil Service, and speaking to you today, I should be more than human if I did not wish to begin with some reflections on the Civil Service as a profession. The temptation to do so is the more irresistible because I have been concerned for some years, though not in an expert capacity, with problems of public administration.

In my youth, as was only to be expected in the political conditions of that period, the attitude of the general public was some what critical towards the superior civil services of what was thenBritish India. The competitive examinations for admission to the administrative services were by many regarded as the " Open Sesame " for a fortunate few to a gilded life of ease and luxury. Nor was this to be wondered at, for the conditions of life and work of officials of the superior grades contained all the elements that went to the making of a privileged class-security of

employment, attractive scales of pay and pensions, an assured social position and opportunity for the exercise of authority." Possession", says George Meredith, "without obligation to the thing possessed approaches felicity." Critics were not wanting who thought that the Services, clothed with authority but owing no responsibility to the people, lived in a state of parasitical bliss.

This is, of course, pure caricature. True, the past record of the Civil Service has not been free from blemish. The criticism is not devoid of substance that the Services tended, particularly before the war, to take a rather static view of life, displaying in consequence an undue rigidity of outlook and resistance to change; but this, it will be seen on reflection, is an indictment rather of the Government of the day than of their administrative instruments. Much graver is the accusation that the Services have cultivated an exclusiveness, which gives them all the appearance and character of a special caste. Hesitant to identify themselves with the life around them, so it is said, they live in a world of their own, unrelated to reality; so isolated, they have developed habits of thought and speech unfamiliar to the great mass of their countrymen.

It would help towards a better understanding, though it might not be comforting, to know that the tendency for groups of men with occupational bonds to form themselves into a selective class is not a new phenomenon. Listen for a moment to the "Economist" on the subject of the public service in the United Kingdom. "All organised Services", says the "Economist", "which are proud of their high standards tend to be close corporations, and by no means all the motives for these instincts of exclusiveness are unworthy. But the Civil Service has seemed to become a closer corporation in proportion to the need for it to be more open. Higher civil servants have become dedicated men and a combination of choice and circumstances has cut many of them off from their fellowmen beyond the pale. They work long hours in their offices: they dine only with their colleagues... The hours they keep have killed their outside interests... The burden of secret knowledge they carry—or, in some cases, the even heavier burden of knowing that they alone really understand the complex issues with which the public besports itself—inhibits the freedom of conversation with the layman." By comparison, the Indian scene does not look too dismal. The barriers that existed in an earlier political setting between civil servants and the community they served are progressively disappearing. When these barriers have been completely broken down—and this calls for effort as much on the part of the public as of the Services—then, indeed, the erstwhile "bureaucrat" will be acclaimed as the true public servant.

True it is again that there have been, more particularly in recent years, distressing instances of oddities and aberrations of conduct on the part of individual officers, which have sullied somewhat the high reputation which the superior services have enjoyed for integrity. Nothing would be more greatly welcomed by the Services themselves than measures, however stern, to eradicate this growing evil. Yet it is well to remember that the unfortunate lapses which have been noticed are no proof of a *malaise* peculiar to the Services. They are rather the result of a general deterioration in moral standards which has affected almost all departments of public life since the beginning of the last war. For this deterioration, the causes are to be sought in certain basic deficiencies of character, in the removal of which, by precept, example and training in the adolescent phase of a man's life, the Universities can play so great a part.

Having said this, we owe it to ourselves to recognise that, despite their imperfections, India's Civil Services rank high among such services in the world. Indeed, Mr. Paul Appleby, a friendly but detached critic, records in his recent report that "India in these Services shares with Britain the distinction of having the best body of generalist civil servants in the world". Those engaged in the higher grades of public administration in our country need not fear comparison with public officers in advanced countries in competence, public spirit or devotion to duty. Their work has largely remained anonymous, but history will record that at a most critical time in our annals, immediately before, during and immediately after the partition, the Services did a unique job in a manner worthy of their highest traditions.

But I am concerned more with the future than with the past. The war and, later, more decisively, the advent of freedom have wrought a revolutionary change in the functions of the civil servant. Up to the outbreak of war, the administrative services were concerned mainly with the maintenance of law and order, with such responsibility for administration of justice as was ancillary to it, and the collection of revenue. Beyond these traditional functions there lay a range of specialized duties connected with such matters as trade and commerce, industry, shipping, labour and the like Initially of limited scope and purpose, these duties grew steadily but perceptibly, in proportion as the principle of *laissez faire* diminished in importance as a determinant of government policy. It was not, however, until the impact of the war began to be felt on the economic life of the country that civil servants found themselves having to perform a wide variety of complex duties wholly unfamiliar to them in the past. With independence came a further and more impressive addition to their duties, with a shift of emphasis from the purely regulatory to service functions. Our goal is the modern Welfare State. Realisation of this goal involves the rapid development of the human and material resources of the country, the elimination of poverty and want, provision of employment and the creation of a just social order. It is to this gigantic and stimulating task that the modern civil servant has to address himself.

What manner of man is the new civil servant to be? He should, it is clear, possess the traditional service virtues—efficiency, integrity and loyalty, more especially to policies and institutions. But of one supposed virtue, that of neutralism in matters with a social or suspected political content, he must rid himself. It has for long remained an unchallenged maxim that the perfect civil servant must be completely neutral from a political point of view and prove himself the loyal and obedient instrument of whatever party is in power. If this means that the model civil servant should create a political vacuum in his thinking, it is a doctrine which must be discarded. Every citizen, whatever his calling, has the right to develop and hold his own political views. With this right there can be no interference. But it is the duty of all public servants, as it is of students, not to become political partisans or to engage in political activities. Fortunately for us, the ideal of a Welfare State is not in our country a controversial political issue; it is the goal laid down in the Constitution itself. Far from being a neutralist, the public servant of today, and still more of tomorrow, should be one rich in human sympathy and with a fully-awakened social conscience. To his work he must bring not only competence but faith and fervour and a mind, receptive as well as constructive, able to see, beyond the immediate difficulties, the opportunities that lie ahead.

This does not mean that the public servant should degenerate into a "yes-man". But it does mean that he should on no account be a "no-man", the man who can only see snags and pitfalls and whose instinctive reaction to external stimulus is one of obstruction. The yes–man tries to please others, the no-man pleases himself; the yes–man does not reveal his mind, the no-man has no mind to reveal. Both species are a danger to any organization, but the no-type is a greater danger at a time of growth and development.

In a parliamentary democracy, such as ours, the permanent services form a vital part of the apparatus of government. Governments may change, and with them national policies, but the varied, continuing tasks of administration are carried on uninterruptedly by the vast complete machine that the public services are today. It is the increasing realisation of the role of public services in the modern State, rather than prejudice and hostility, that accounts for the recurrent and occasionally extravagant interest shown in the reform of the Services. The Services have lost something of their former glitter and allur, but have gained enormously from their functions having been more intimately related to the fulfilment of a national and social purpose. The field of public administration has at the same time been greatly enlarged; this extends now to social services, State industrial and commercial enterprises, shipping, regulation of trade and so forth. Further, the Services have been leavened with new types of recruits—scientists, economists, university teachers and technical experts

—who have brought richness and variety to their new profession. So widened and diversified, the Civil Service is, and will continue more than ever to be, as honourable a profession and one providing as wide opportunities for national service, as any open to youth. Though service under the Government should cease to be regarded as the most desirable form of service, I hope the Civil Service will continue to attract a proportion of the best type of young men and women trained in our Universities.

Conventionally, this is an occasion when it is the prerogative of age to give to youth advice and admonition. I do not wish to exercise this prerogative, not only because I am myself somewhat allergic to unsolicited advice but because being in my fifties, I am again in a period of youh—the youth of old age Nevertheless I feel sure you will permit me to share with you certain thoughts that come to my mind when I reflect upon the experiences of my own life. Having said that, let me hasten to explain that my intention is not to reel off the familiar copy-book maxims in the manner of a moralist, but merely to place before you the fruits of my own experience.

The purpose of education is manifold; it develops the intelligence; it builds up character; it is in its best known sense the imparting of instruction, academic or technical; and it trains the emotions. In the highly specialised and highly competitive world of today, there are not many who have the time, the means, aptitudes or opportunities to be educated in this complete sense. Education is becoming fragmentary, and each man seeks to acquire the *expertise* appropriate to his limited field. Is there something it may be asked, that every man, whatever his individual branch of work or interest, should possess, if he is to be properly equipped to go through life? To this question I would unhesitatingly give the answer that something is character. Character is a complex of attributes, determining the motives and actions of men. Without it, all else is of little avail; indeed, intelligence without character is a source of danger both to the individual concerned and to his fellow-men. The foundations of character are laid in one's early days, but its development is a life-long process, calling for patient and assiduous effort. Looking round, one is saddened by the woeful blemishes and deficiencies of character so conspicous in life today. Yet, at no time in our history, has the need for character national as well as personal, been more insistent than it is now. We as a nation are dedicated to the supreme task of creating on a democratic basis the conditions of an ample life for all our people. The achievement of this purpose calls for qualities of the highest order. We are well endowed by Nature in things of the intellect; but the priceless asset of character, without which effort falls short of achievement, we have largely to create for ourselves. Upon you, my young friends, rests the responsibility for building up the asset, and you will, I am confident, approach life with a full sense of this responsibility.

I hope you will bear with me if I speak to you for a while about certain well-known instruments of character training. One is discipline. I know that to many the word has an ominous ring, so let me make it plain at once that I do not refer here to the form of discipline preached and enforced by despots and dictators. Authoritarian discipline exacts blind and unquestioning obedience; it destroys initiative, suppresses personality, and has for its object the regimentation of thought and action. It is not of this type of discipline that I wish to speak, but rather of the cultivation of mental training and, more particularly, of disciplined conduct, in the sense of the willing observance by the individual, for the common good, of a code of conduct or behaviour enjoined by the group or society of which the individual is a member. Corporate existence develops certain patterns of organisational relationships. Disciplined conduct consists largely in the recognition of such relationships and in the respect given to the obligations arising therefrom. Without discipline, there can be no true leadership, and without leadership, no collective pursuit of common aims. In the preparation for citizenship, therefore, it is just as important for the undergraduate to develop a sense of discipline as to improve his knowledge. Teachers and scholars, in association, together form the community called a university. Loyalty to this community as a whole, rather than to sectional interests, lies at the base of University discipline.

Is it too much to hope that the students of this University will be the first to dispel any doubts that may exist as to the general acceptance by the student community of this primary loyalty?

Closely allied to the cultivation of discipline and of equal importance, is the fostering of the team spirit. We, Indians, are highly individualistic by nature, and fall easy prey to forces of disunion. For many of our past misfortunes, our aggressive individualism has been largely responsible. Yet, even today, in every department of life, our accepted motto seems to be " every man for himself ". Self-discipline is not by itself a sufficient corrective to this traditional frailty. The capacity for sub-ordinating personal interests to those of the group can only be developed by training in responsible co-operation. There is no greater need today than for young people to create for themselves new opportunities for such training and learn the art of working together in harmony and understanding. Lord Ismay, Secretary-General of the North Atlantic Treaty Organization, tells how a magnificent body of troops which had been selected for special service from about forty different regiments, of which he was in command, was nearly put to rout, because they had not had the chance of becoming a team. He proceeds, " But it is not only in battle that unity counts. During World War II, I headed Sir Winston Churchill's defence staff. It consisted of all sorts of men and women—soldiers, civilians, economists, statisticians, clerks, typists, and so forth. It was fortunate that we became a happy family from top to bottom and that every man and woman thought of the team rather than of himself. Dead tired though we used to be at the end of the day, no one ever dreamt of going to bed if there was anything he could do to help anyone else". It is that spirit which should guide and inspire us, the spirit of joyous comradeship in work that knits us together by a sense of oneness.

I now come to a theme which is close to my heart, the theme being the practice of non-attachment. I treat of this, not philosophically, because I am not competent to do so, but empirically, as a person engaged in the common tasks of this work-a-day world. Non-attachment sounds frigid; it suggests aloofness, unwordliness and emotional emptiness. Yet, philosopher would tell you that it is the perfect summation of all positive virtues. To the common man it means in practice the conscious separation of self from the things to which it tends to get attached. Enthusiasm in a good cause is a commendable thing; but it often springs from the identification of self with the cause; and it gains in quality and intensity, when thought of self is divorced from advocacy of the cause. The ideal of non-attachment is the monopoly of no country or religion; but it would probably be true to say that this ideal was propagated and practised more widely in our country than in any other. Yet, despite the air of moral superiority which many of our countrymen assume, pardonably perhaps, in the first flush of independence, the practice of non-attachment seems to have fallen into desuetude in our own country. Here, as elsewhere, self is becoming more and more the dominant factor in one's life. Hence the mad scramble for advancement that we see all round us: hence careerism in official life; opportunism in politics; and unprofessionalism elsewhere. The canker is even affecting youth. Some weeks ago I asked an Indian Foreign Service probationer what foreign language he had selected for special study. He said Arabic, and hastily asked me, " Is it all right from the point of view of a career?" The question distressed me, for, though I did not think the young man was typical of his generation, his attitude did indicate the existence of influences unwholesome to youth. It is a natural and honourable ambition to want to make the best our lives, but to achieve this ambition the golden rule to follow is, " plan for service and the success of your work; but do not plan for your personal success ". It is astonishing, however, how personal success often pursues those who flee at the sight of it. An intimate friend of mine, whose qualities and attainments are only matched by his selflessness, today occupies one of the highest positions that the country can offer to any man; yet throughout his life he has been singularly lacking in personal ambition. Life, now as of yore, showers its richest prizes on those that do not seek them.

Graduates of the University, you are taking your place on life's stage at fateful hour in our

history. Behind us lie the first six years of our independence,—normally, too short a period to make any significant impact on the life of a nation. Yet those six years have witnessed perhaps greater change and growth than any similar period one can recall; they have been years of unceasing activity over many phases of national life. Politically, the country, so long torn into disparate units, has been welded into a single whole, and enjoys the blessings of a Constitution founded on principles of justice, liberty, equality and fraternity. The deep wounds left by partition are slowly healing, though the scars may long remain. Economically, we have weathered many a storm, and have sailed into calmer waters. Production is increasing, and even the intractable food problem is becoming less so owing to the combined effect of Nature's favours and the artifice of man. Abroad, in the international sphere, ours is a voice that is listened to, wherever nations gather; it is not a voice that is universally liked, but it is a voice that is widely respected.

Yet at this moment we are battling for our survival. Asia is bestirring herself after the slumber of ages. Whatever the form of government and the system of political philosophy in each country dynamic forces are at work throughout the great continent, urging men forward to a rapid realisation of tneir age-old dreams of progress, political, social and economic. The race may not always be to the swiftest, but it never is to the hindmost. India, the second most populous country in Asia and indeed of the world, cannot afford to tarry. Her millions, for long victims of poverty, ignorance and disease, yearn for the opportunities of a richer and fuller life. If in these hopes they are disappointed, life will pass us by, with never a chance for us to gain the place that is our due.

The Five Year Plan is our first attempt to translate into action our concern for our fellowmen. The task upon which we have entered is nothing less than the full-scale reconstruction of our national economy and our social structure. We see planned development as a means of enlarging freedom and for creating new opportunities for young men and women. In a book of great delicacy of feeling and expression, "Memory hold the door", John Buchan writes:—

> "In my lifetime I seem to note a change which is graver than our other discontents, which, indeed, is in a large measure the cause of them. The outlook of youth has been narrowed, doors have been sealed, channels have silted up, there is less choice of routes at the cross-roads".

Written in another clime and of another society, this might well seem to present-day Indian youth a true description of the conditions of his own life. Over youth today lies a brooding disquiet. Yet as our economic and social apparatus is being improved and re-fashioned, there is coming into view, beyond the traditional avenues of employment, the prospect of widened opportunity for youth. Not least, in the expansion of the social services, there lies promise of new vistas of opportunity for those dedicated to national service.

For planning to achieve its purpose, there has to be a rapid advance, both in the development of material resources and in the reconstruction of values and attitudes. The large number of projects, now under execution, will add substantially to the country's potential for production. The annual investment on development programmes has increased steadily since the first year of the Plan, and will, it is expected, be doubled during the next two years. Already, in agriculture, irrigation, power and industrial production, encouraging results have been obtained, though the best gains are in all conscience small enough in relation to our needs.

In the re-shaping of common values and attitudes, community projects and the extension services, which form a vital aspect of the National Plan, have a considerable part to play. In more than forty thousand villages to which they now extent, the welfare of the peasant and the worker lies at the heart of all public activity. Public Servants of all grades work for this common goal, together with the people, serving them and helping them with all means in their power. To young men and women, fresh from school and college, community projects offer a

rich and expanding field of service. They have there the opportunity to identify themselves with the best interests of large numbers of their fellow-beings and to promote a new and better way of life. This will make their own work so much more worthwhile and so much more satisfying. It may well be that the common bond of fellowship so created between social elements, hitherto dissimilar, will be the truest measure of success of the national reconstruction, begun under the Five Year Plan.

The appalling poverty of our country has led the framers of the Plan to place their main emphasis on the raising of the people's standard of living. They have done so advisedly, for the pursuit of spiritual progress and the cultivation of moral values are not for those who are ill-fed, ill-clothed and ill-housed. First things first; the material requisites of civilised life are today what we most need and must first secure. Nevertheless, we should from the first be on our guard lest with the growing enjoyment of the material amenities of life we should develop a materialistic attitude to life. This is the age of scientific inventiveness and technological progress. Each day brings its crop of inventions, some beneficent, some quite otherwise, merely creating unwanted needs, and serving no higher purpose than to be-muse and dull the senses. Legislation and labour-saving devices are creating more leisure, but for the enjoyment of leisure men are relying more and more on external stimulation. Speed and noise are inseparable from the physical working of machinery; and in this industrial age speed and noise bid fair to become the most indispensable elements in all popular forms of entertainment. Amid this din and bustle, who can find the time today to cast his eye inward, or to turn to a page of exquisite writing, and, in Charles Morgan's fine phrase, "without knowing that we have ceased to read, allow the book to rest, and look out over and beyond it with newly-opened eyes, discovering all else?"

We should be foolish if we attempted to limit the ever-widening scope of man's inventive genius. But we should be still more foolish if we permitted human personality to be dominated by the creations of man's inventive brain. Here it is that our past can shape our future. Earnestness of purpose and reformist zeal need not blind us to the virtue of the traditional graces of life—courtesy and consideration, kindliness, tolerance, charity. Nor must we allow the material appurtenances of life to beguile us into a mood of pride and self-satisfaction. From our rich heritage, spiritual and cultural, we must draw that wisdom and understanding of life which will give us in a world becoming progressively more materialistic, poise and serenity, a sense of values and perspective and a vision of enduring things beyond the realm of physical experience.

Graduates of the year, you have now completed your academic training, and upon that training the University which has tended and nurtured you has set its seal of approval. You now go forth into the world. Go forth into it with faith and courage. Countless generations of human beings have traversed life before you. Yet life remains an adventure, new and strange as it ever was. To you, new graduates, setting out on that adventure, pressing forward, in hope and wonderment, with the eager eye and pure enthusiasm of youth, to see the scroll of life unfold: to you all, my young friends, I wish God-speed and good luck.

Flumes for Flow

(Certain Aspects)

A flume like "the natural water falls, natural weirs and orifices through which the flowing waters gush across" is also a natural phenomenon in a river which during its run, is obliged to constrict on account of natural impediments abutting its margins.

There are also artificial flumes across Rivers and water courses which are meant to serve specific purposes. Two of these are considered below:—

1. Flumes for economy in canal costs

A canal in cutting costs a lot of money and the outlay increases if the width is large and the cutting is through rocky strata. In such regions a compromise is effected and the costs cut down by fluming the section which process involves curtailment of bed width with suitable increase in depth so as to maintain the optimum section required for passing the requisite discharge. The appurtenant works for such a "flume" are a gradual constriction from the natural bed width section followed by an approach transition, the throated flume, and the reversing process to regain the original section by a departure transition and a gradual flaring out.

A typical instance is the fluming proposed for the Kistna Pennar Canal at the Mittikondla Ridge cutting, the scope of which is described below:—

The proposals for linking the reservoirs across the Kistna Pennar rivers by the Kistna Pennar Canal involved the cutting of the watershed between them for a total length of 4 miles with a maximum height of cutting of 100′ for about a furlong or more. To minimise the cost of cutting, fluming the canal in the cutting region was proposed by suitably reducing the bed width and increasing the F.S. depth and velocity.

The sub soil at the site upto the required depth of cutting was found to be shale rock which required lining to effectively prevent seepages and minimise loss of head by friction. This decided the permissible maximum velocity in the flume to be of the order of 12 F/S. The area of water section required to pass down the 75,000 cusecs proposed with this velocity is of the order of 6250 sq. ft. which was proposed to be obtained by adoption of suitable reduction in width and by increased depth of flow in the flume region. The F.S. Depth in the region above the flume was 42 ft. and this was increased to 60′ in the flume (*i.e.* by about 40 per cent extra) and the corresponding bed width required worked out to 74′.

The details of fluming section as proposed are furnished in reverse page :—

For its inherent advantages as described above, "fluming" has also been resorted to in a number of places in the Tungabhadra Project Canals.

2. "Flumes" for measurement of "Flows".

In certain cases, specially where the discharge to be measured up is nominal a special type of flume is better fitted for the purpose than a conventional weir.

This is because "in the flume the velocity of the water and hence its kinetic energy, after passing through the narrow throat is maintained or preserved, whereas in the case of weirs this velocity and this energy is almost entirely lost.

The result of this is that a large proportion of the "head" or energy causing the flow through the flume is recovered on the downstream side and reappears in the form of a 'Standing Wave'.

The nett difference in level between the upstream and downstream is reduced to a minimum and the flow may be measured accurately just as in a weir although it may appear to be more or less drowned. A comparison of weir and flume measurement where the width of flow and effective head is 12" in both cases is shown in the rear cover page.

The main advantage is therefore in the saving of "Head" which is also exhibited in a lucid manner" in the rear third cover page.

The formula for the discharge through measuring flume is

$$Q = 3.224\,H^{1.49}\,B^{1.11}\,(B + 2\,H)^{-0.11}$$

where B is the width of throat and H the head above it. This elaborate formula takes into account the various factors such as proper design of the shape of inlets and outlets; lengths of throats factor producing the standing wave; the velocity of approach, friction in the flume etc.

Several types of measuring flumes have been evolved and a typical one is a "Parshall's Flume" The main features are

(i) A level inlet with its sides constricting at an angle of $\tan^{-1}(1/5)$

(ii) A throat with a sloping floor of 1 in 3

(iii) A "reverse sloped" exit with it sides flaring out at an angle of $\tan^{-1}(1/6)$

The side of the inlet is increased with respect to the flume width according to the formula $W/2 + 4'$ where W is the width of the flume in feet. The discharge, when the downstream head does not exceed 70 per cent of the upper head, is given by the formula

$$Q = 4\, W\, Ha^{1.522\, W^{0.226}}$$

Where W = width of the flume and Ha = upper head in ft.

The cumbersome formula can be simplified for all practical purposes to the form

$$Q = 3.90\, W\, Ha^{1.53}$$

The main feature of the rating of Discharges by means of specialised flumes lies in the simplicity in observations as nothing more than a single measurement of the upper head is required. In routine weirs different formula for different conditions of flow such as (1) clear overfall (2) drowned, have to be applied and depths of flow measured in a number of places as will be seen from the following :—

$$Q = 3.1\, L\, (h + ha)^{3/2} - ha^{3/2}$$

Drowned

$$Q = \frac{2}{3} C_1 L \sqrt{2g} \left[\left\{ (h+ha)^{3/2} - ha^{3/2} \right\} + C_2 L d \sqrt{2g\,(h + ha)} \right]$$

Where L = length of the weir
h = actual head of discharge
ha = head due to velocity of approach
d = depth of tail water on crest
C_1 = 0.577
C_2 — varying from 0.60 to 0.95 for different depths of tail water over crest.

Thus, these flumes on account of their ability to operate under silt laden conditions without difficulty, their capability in standing up to a high degree of submergence, the relative ease in their operation and absence of many parts, are eminently suitable for minor distributaries of irrigation systems where routine types of weirs would result in considerable loss of available head.

Sketches of a typical (1) canal flume for economy in cost and (2) A measuring flume are also given in the back rear page.

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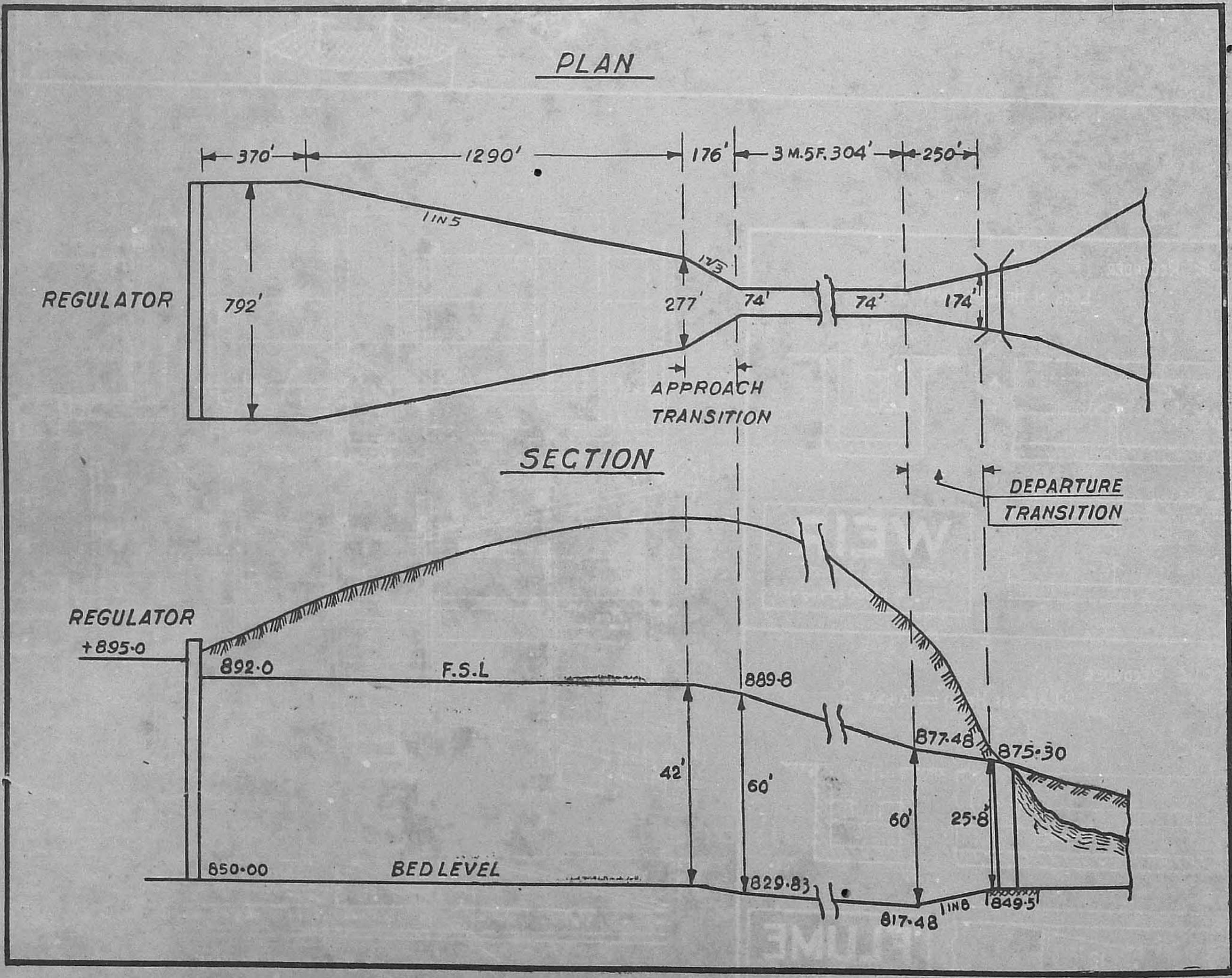
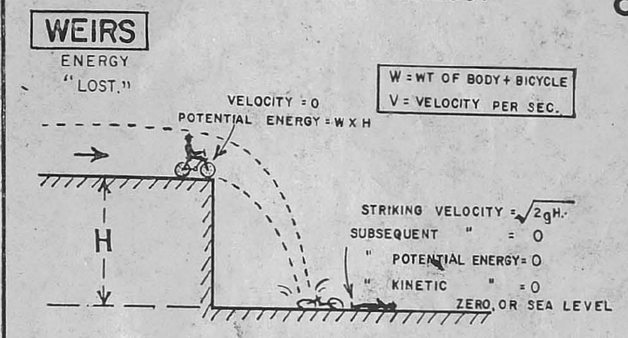
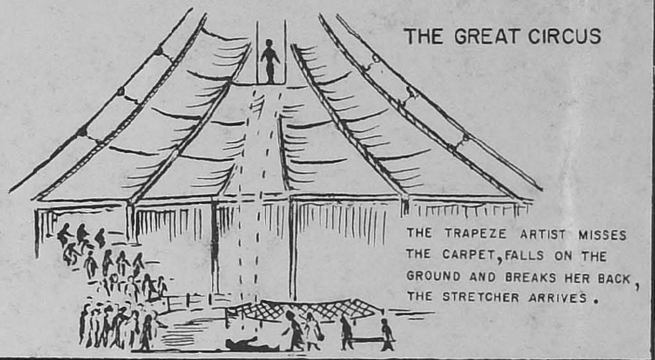
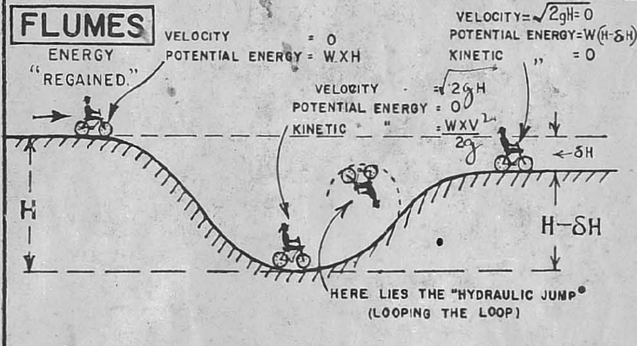


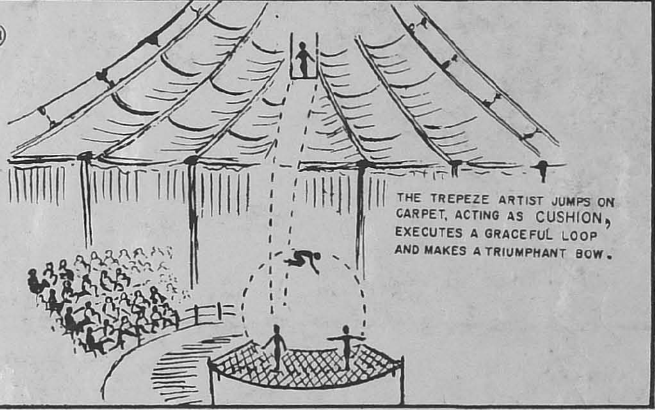
MAIN DIFFERENCE BETWEEN WEIRS & FLUMES

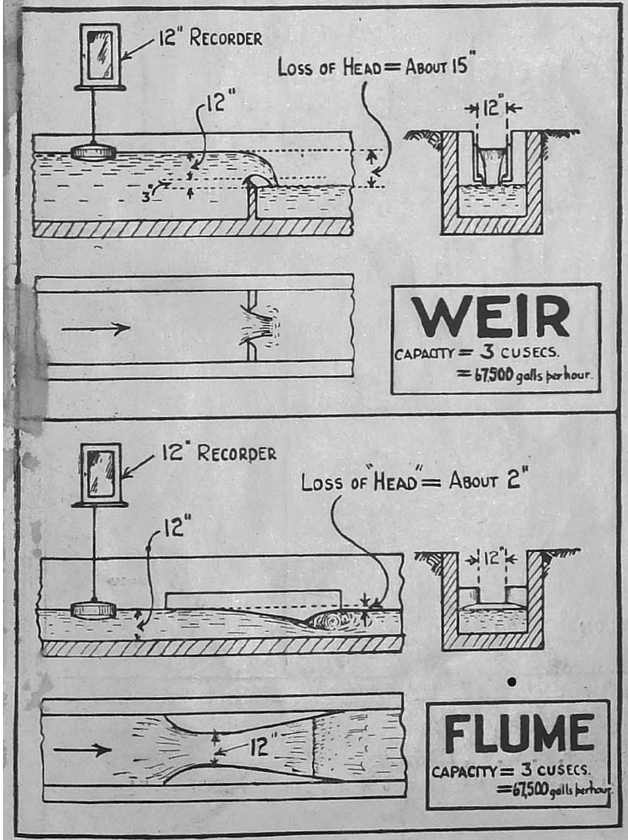
A CRUDE & TRAGIC ANALOGY & AN ILLUSTRATION FROM REAL LIFE

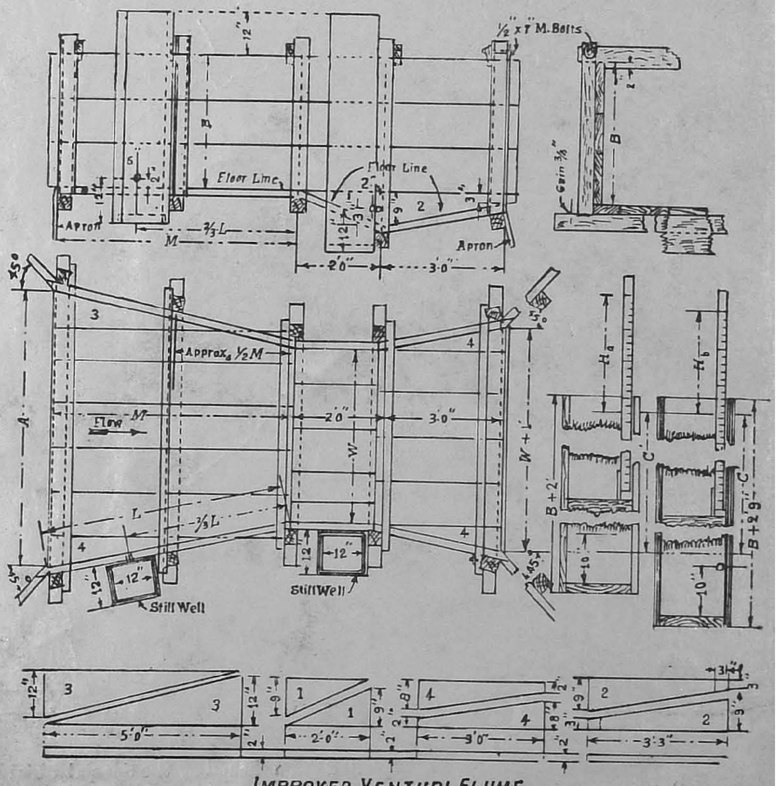












IMPROVED VENTURI FLUME

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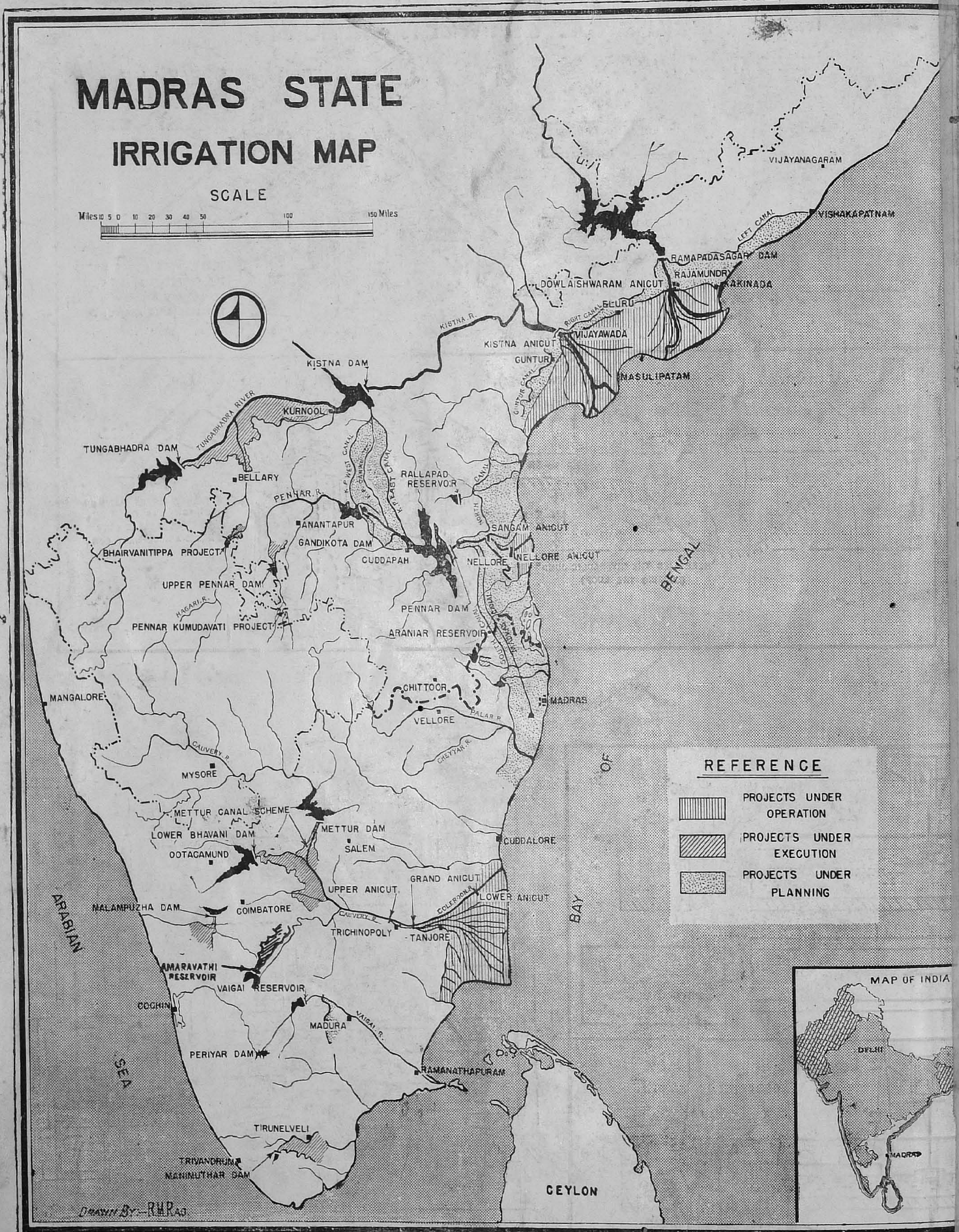

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